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"NATIONAL" BULLETIN

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"NATIONAL" PIPE IN LARGE BUILDINGS

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EQUITABLE BUILDING
New York City
Said to be the Largest Office Building in the World
(See page 19 for description)

FOREWORD

PROBABLY no other field of progress is more typical of the large vision of the modern business man than the mountain-like buildings—in his terse argot well-named "sky-scrapers"—which he erects for the official and clerical departments of his business; the palatial banks where in almost regal splendor he transacts the financial operations of the nation; and last but not least the imposing structures, whose walls seem unending rows of steel-framed glass, where he manufactures hundreds of different products or generates power to supply the needs of a great city.

The cramped, dark, wholly uninviting and generally unsanitary and uncomfortable buildings, still in use in London and many other European cities, may be taken as examples of the earlier point of view that any place was good enough for offices. Millions have been amassed in the dingiest quarters in old London, and it is nothing unusual for the man who lives his nights in a palace to spend his days in a dingy old building, surrounded by the undisturbed dust of years, and the shabby discomfort of his great grandfather's office furniture. The wretched and disgraceful factory conditions in all countries are too recent to be entirely a matter of the past, even in some of our finest cities.

But these conditions are rapidly changing even in conservative Europe, while in America few office buildings more than thirty years old are to be found in the heart of any large city—indeed, some buildings considered fine even twenty years ago cannot command paying rentals and are therefore torn down to make room for the latest type of steel building construction.

Previous to ten, or at most fifteen years ago, the value of "NATIONAL" Pipe for interior uses in large buildings was not wholly recognized. The reason is not far to seek. The first steel pipe (about 300 tons) was not made and marketed until 1887, only twenty-eight years ago, yet today approximately 90 per cent of the entire tubular production in this country is steel! This unparalleled increase in the production of steel pipe, as an industrial and commercial success, is shown in statistics published by the American Iron and Steel Institute (Special Statistical Bulletin No. 8, 1914). With the modern steel "sky-scraper" has come the modern steel pipe, therefore much of the pipe taken from razed buildings (antedating fifteen or twenty years ago) would not be more suitable for modern buildings than are the great oak timbers which have been replaced by modern steel beams.

As a logical consequence, those who are about to erect a great modern hotel, office, bank, factory or similar building should secure the most dependable material—whether it be the steel construction, the water, gas, steam or other pipe lines, or the most insignificant detail in every part of the building.

As concrete examples, consider some of the more recent buildings erected—the Equitable Building in New York City, for instance. This building replaced a structure which, at the close of the civil war, was considered the "finest office building in the world", was one of the first attempts at fire-proof construction (but was destroyed by fire), and contained the first passenger elevator ever installed in an office building. The new Equitable was planned and designed by one of the world's famous architects and, judging by results, nothing has been spared which would enhance the majesty of the design or minister to the welfare and convenience of the tenants.

Is it not significant that for such a building "NATIONAL" Pipe has been specified for all heating and plumbing lines, except where, for special reasons, brass pipe has been used?

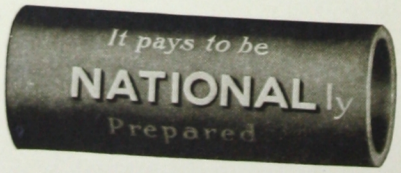
Is it conceivable that those halls of glistening marble and mosaic—the bronze—the stained glass—the mahogany and other expensive woods brought from far-off lands, and all else that is included in the 38 stories of this wonderful building should be jeopardized by pipe installations about which any doubt existed? That would be commercial insanity. No; "NATIONAL" Pipe was specified because the builders were convinced that "NATIONAL" Pipe suited their purposes most effectually.

The "*Real Estate Magazine*" for February, 1915, an issue devoted to a description of the Equitable Building, states in "The Epic of the Equitable"—

> " * * * the only way the owner can make a profit on his investment is to know the material at first hand, how his building is being reared, *and the nature and quality of the material and equipment that go into it.*"

Evidently the owners and builders of the Equitable Building recognized the advantages accruing from "NATIONAL" Pipe installations in other equally important buildings and knew the value of "NATIONAL" Service.

The pipe lines of the "sky-scraper", and other types of modern buildings, are of such importance to their successful operation that it has seemed advisable to include in this "NATIONAL" Bulletin certain engineering data relative to the subject. (See pages 54 to 78.) This information should be not only of interest but also of valuable assistance to the architect and engineer in designing the several piping systems; to the contractor in the construction and installation; to the engineer who is entrusted with the operating and in short to all who are interested in the economical and efficient operation of the completed building.



"NATIONAL" PIPE SERVICE

THE commercial success of any product is in direct proportion to its proved ultimate usefulness and satisfactory service. "NATIONAL" Pipe is the resultant knowledge accumulated throughout more than fifty years' experience in the specialization of pipe manufacture. Practical mill experience has been, and is, combined with scientific research in the laboratory and trained investigation in the field of actual service, aided by careful study of conditions and requirements in all branches of tubular service.

From the first year (1868), when "NATIONAL" Pipe was made in a little mill in Boston, Massachusetts, down to today, it has been the constant aim to so improve materials and manufacturing processes that "NATIONAL" Pipe shall prove 100 per cent efficient in service.

The architects, engineers, contractors, owners and others interested in the construction and operating success of the large and prominent commercial and industrial buildings illustrated in this Bulletin, have attested by their specifications their recognition of the value and efficiency of "NATIONAL" Pipe.

The statistics compiled by the American Iron and Steel Institute[1] show that approximately 90 per cent of the entire tubular production in this country today is steel, and this is concrete evidence of the position occupied by steel pipe—"NATIONAL" Pipe—in the Engineering, Architectural and Industrial world.

The following brief statements are a few of the many advantages of "NATIONAL" Pipe.

FULL WEIGHT All "NATIONAL" Pipe is Full Standard Weight—no "merchant" or light weight grades are manufactured in "NATIONAL" mills. When "NATIONAL" Pipe is specified and received, the substitution of inferior, light weight pipe is automatically prevented.

PERMISSIBLE WEIGHT VARIATION A careful check upon the shipments of "NATIONAL" Pipe, during a recent month, showed nearly 80 per cent of the sizes were slightly heavier than listed weights, and only 20 per cent were 3 per cent (or less) under weight. (A variation of 5 per cent is permissible.)

PROMPT SHIPMENT Mill records for a recent year show that 95 per cent of all promises of shipment were fulfilled.

COMPLETE LINE There is a "NATIONAL" Pipe for every purpose; National Tube Company manufactures a complete line of tubular and allied products, therefore it is not necessary to specify and use several different makes of pipe.

CAPACITY The manufacturing capacity of the eleven plants of National Tube Company is upwards of a million and one half tons of tubular and allied products per annum.

ONE ORGANIZATION All materials and processes, from the ore to the finished product, are controlled within one organization, thus assuring one high standard of "NATIONAL" quality.

[1] Special Statistical Bulletin No. 8, 1914, American Iron and Steel Institute.

SPECIALIZATION The entire organization of National Tube Company is engaged in the manufacture of "NATIONAL" Tubular and Allied Products—therefore, "NATIONAL" Pipe is a specialized product.

MARKING The name "NATIONAL" is rolled in raised letters on every length of "NATIONAL" Pipe. This mark prevents substitution. Always look for the name "NATIONAL" when you receive your pipe order—if the pipe is not marked "NATIONAL" it is NOT "NATIONAL" Pipe, but an inferior substitute.

TESTED "NATIONAL" Pipe is tested and inspected at each important step in the manufacturing processes. In this way only, can the high standard of "NATIONAL" quality be maintained.

UNIFORMITY Uniform material is obtained by "NATIONAL" methods of manufacture. The variation in physical and chemical properties from year to year is almost negligible. For example, the carbon content varies less than .01 per cent in a year.

THREADS Clean cut, strong, durable threads are readily obtained on "NATIONAL" Pipe with proper dies, and assure non-leaking, efficient joints.

DUCTILITY The ductility of "NATIONAL" Pipe is an important feature in the making of bends and coils.

DURABILITY Hundreds of service tests have proved that "NATIONAL" Pipe is uniform in structure, and thus the natural tendency to corrosion is reduced to a minimum.

SPELLERIZING The smaller sizes (4 inches and under) of "NATIONAL" Pipe are Spellerized to reduce the natural tendency to corrosion and add to length of service. The Spellerizing process is probably the most important improvement in pipe manufacture in the last twenty years.

RESEARCH DEPARTMENT Thousands of dollars are annually apportioned by National Tube Company for the investigations of the Metallurgical and Research Department into conditions of manufacture and subsequent service, all with one end in view—to increase the efficiency of "NATIONAL" Pipe service to the consumer.

ACCURACY "NATIONAL" Pipe is especially suited for work requiring accuracy, as the variation in diameter and wall thickness is almost negligible.

"NATIONAL" BULLETINS This phase of "NATIONAL" Service is of value to many industries, for "NATIONAL" Bulletins contain authoritative engineering data relative to tubular and allied products, and are highly regarded by the architectural, engineering and allied professions as materially educational in scope and purpose.

"NATIONAL" SERVICE "NATIONAL" SERVICE IS NOT A VISIONARY, IMPRACTICAL ABSTRACTION—BUT A DEFINITE CONCRETE ACTIVITY.

THE ADVANTAGES OF MARKING A PRODUCT FOR IDENTIFICATION

THE advantages derived from identifying "NATIONAL" Pipe, by rolling the name "NATIONAL" on every length, is emphasized by the following editorial which gathers the composite experiences of architects and others who write specifications for building materials—of which pipe is one of the most important—and presents a broad survey of present conditions. This editorial appeared in *The American Architect*, October 1, 1913, (page 131).

Selection of Trade-Marked or Definite Building Materials

"The disappointment of clients, consequent loss of the architect's prestige, and a multitude of minor evils, result too frequently from the 'or equal' clause, still used to some extent in building specifications. When after thorough investigation an architect is convinced that a certain article or material is exactly suited to the needs of his clients it would seem that he should say so without hesitation or further discussion. To specify what is right, 'or equal', in the first place discredits the architect's judgment and experience and is a tacit admission that he may have committed at least a technical error in specifying a particular article. From the time this iniquitous clause is made public until construction of the building is practically complete the architect must, to keep within the spirit of the specifications, listen with whatever patience he can command to the rival claims of each manufacturer whose goods are possible components of the future building. And then he must use his own judgment as to a possible substitute just as he presumably did when first drawing up the specifications. After such reflection, the old excuse that the 'or equal' clause is inserted to give others a 'chance' and to prevent charges of favoritism loses its potency. Such accusations are as old as tradition, and now, as then, should have no weight where motives are just and sincere. When a reputable doctor prescribes a given drug under given conditions no one thinks of charging him with partiality toward its manufacturer, and similarly an architect should be able to specify a definite article without having his motives impugned, or, if they are, he should be able to rise above such malicious insinuations.

"But when a certain article or material has been selected, how is the architect, or his inspector at the building, to know that no substitution has been made by an unscrupulous contractor or dealer? In these days of clever imitation even the most experienced superintendent may be readily deceived by mere casual inspection, and exhaustive tests of each item at the building are impracticable. The only satisfactory answer to the dilemma seems to be the exclusive use of trade-marked materials, or materials which are clearly marked as to quality or grade by the manufacturers. An article that is *not good enough* to be trade-marked, or bear evidence of grade backed by the maker, is not good enough to specify. Aggressive manufacturers in nearly all lines of trade have found some method of distinguishing their products and thus have accomplished what might be termed four-fold protection. By preventing substitution of another article for that of their own manufacture, they assure to themselves the full benefit of their extensive advertising, they assure to the consumer the satisfaction for which he is paying, they assure to the architect certainty and ease of identification, and they assure to the contractor and dealer freedom from possible charges of dishonesty.

"We believe that the time is coming when all manufactured articles entering into high class construction will be readily identified by a trade or other distinguishing mark, and the use of all others generally avoided. Even now the adoption of a rule to use only materials falling under the above classification would not seriously restrict an architect in his selections."

AUTHORITIES ON STEEL PIPE

THE durability of steel pipe has been definitely and affirmatively demonstrated. Hundreds of independent service tests and investigations by disinterested engineers, by leading universities and technical schools and the research departments of a number of municipalities, industrial corporations and similar unbiased investigators, have proved beyond question that:

DURABILITY OF STEEL PIPE RECOGNIZED

"Taken on the average there is no difference in the corrosion of iron and steel pipe." [2]

"Viewing impartially all of the data presented so far, there seems to be little to choose between wrought iron and steel pipe on the whole, as regards their resistance to corrosive influences, but one point may be mentioned with reference to the manner in which these materials corrode: With steel the rusting takes place more or less uniformly over the surface, while wrought iron shows a decided inclination to form deep pits. That this is a dangerous tendency can hardly be doubted." [3]

The technical editor of one of the leading newspapers[4] in reviewing Mr. Wilson's article from which the above is quoted states:

"To paraphrase an old saying, a pipe wall is no stronger than its thinnest spot, therefore, to the extent in which wrought iron exhibits this defect (pitting) in greater measure than steel, it may be considered correspondingly inferior."

The now acknowledged fact that steel and wrought iron pipe are equally durable however, does not prove that poorly made steel pipe is equal to the best grades of wrought iron and vice versa, for there are many indifferent grades of both classes of pipe on the market.

NATIONAL TUBE COMPANY AT ONE TIME LARGEST MANUFACTURER OF WROUGHT IRON PIPE

At one time National Tube Company was the largest producer of wrought iron pipe in America; but after many years of investigation and research work finally abandoned the manufacture of wrought iron, entirely confining tubular production to steel pipe—"NATIONAL" Pipe—being convinced by the evidence accumulated from actual service results that "NATIONAL" Pipe is superior in durability and physical properties to the best grades of wrought iron pipe on the market.

"NATIONAL" PIPE THE RECOGNIZED LEADER OF WROUGHT TUBULAR PRODUCTS

"NATIONAL" Pipe is today the recognized leader of wrought tubular products. Why? Because, all processes of manufacture being under the control of one organization from ore to finished product (which embraces a full and complete tubular line), there are certain fixed advantages characteristic of "NATIONAL" Pipe; there are

[2] From a paper read by Dr. Wm. H. Walker, Mass. Inst. of Tech., Boston, Mass., at the December 13, 1911, meeting of the New England Water Works Association.

[3] From a paper, by L. C. Wilson—"Wrought Iron or Steel Pipes", Engineering Magazine, November, 1915, pages 253, 254.

[4] Pittsburgh Gazette-Times, November 7, 1915.

the uniform chemical and physical properties; the uniformity of structure which minimizes the tendency to corrosion; the Spellerizing of the smaller sizes which is an additional protection against corrosion; the uniform strength which successfully resists the severe service conditions in the industrial world; the special inspections and tests at all important stages of manufacture which eliminate any imperfect material; the proved durability in service which has demonstrated beyond question that "NATIONAL" Pipe gives a real service—not an imaginary service based on mere claims. (See page 3.)

That "NATIONAL" Pipe stands at the summit of the whole wrought pipe industry—national and international—is evidenced by the fact that "NATIONAL" Pipe was awarded the "GRAND PRIZE" at the Panama-Pacific International Exposition, San Francisco, Cal., by the "Superior Jury of Awards" which consisted of men whose knowledge is recognized as authoritative in their respective fields and whose judgment is disinterested—in fact their judgment is the consumer's verdict of quality and service. Only one "GRAND PRIZE" was awarded in each class of products exhibited.

"NATIONAL" Pipe and allied tubular products were awarded this supreme distinction "as representing the highest development of the art".

The following text contains brief summaries of a number of tests and investigations (referred to above) with the conclusions reached, and the name of the authority who made each investigation.

TESTS

THOMPSON—Prof. T. N. Thompson, in March, 1906, installed alternate pipes of the two metals in a hot-water line, and at the end of a year discovered that steel pipe had approximately 7½ per cent longer life than wrought iron under such conditions. (A. S. H. & V. Engineers, 1906.) **See "NATIONAL" Bulletin No. 4.**

In a similar test carried on by a committee appointed by the American Society of Heating and Ventilating Engineers with iron and steel pipe made by various companies, Prof. Thompson reported:

> "Therefore, a rational deduction to draw from the preceding facts is that steel pipe is more durable than plain wrought iron pipe when used to convey hot water and subject only to internal corrosion. I know that the above summary is not in perfect harmony with the opinions of many engineers and contractors, but I can only record the facts as they are found to be without comment." "The Relative Corrosion of Wrought Iron and Soft Steel Pipes"—T. N. Thompson. (Proceedings American Society of Heating and Ventilating Engineers, Vol. XIV, 1908.)
>
> "This test checks up well with the aforesaid 1908 paper, and we believe demonstrates that modern steel pipe of good quality is at least as durable as modern strictly wrought iron pipe of good quality, and is very much superior to a poor quality of wrought iron in this class of work." (A. S. H. & V. Engineers, 1909.)
>
> "In closing we desire to call special attention to the fact that we find it is not safe to accept reports regarding the corrosion of wrought iron and steel pipes without first identifying the materials, because so many engineers cannot ordinarily distinguish the difference between them." "Report of Committee on Corrosion of Wrought Iron and Steel Pipes." (Proceedings American Society of Heating and Ventilating Engineers, Vol. XVI, 1910.)

COAL MINE CORROSION

> "Corrosion tests in running mine water were carried on by Prof. Thompson, The Pittsburgh Coal Company, H. C. Frick Coal Company and others, these indicating that steel is at least equal to wrought iron in resisting corrosion." (Iron Age, July 12, 1906.)

The results of these tests of wrought iron and steel pipe in coal mines may be gleaned from the following extracts:

> "The results indicate to us that steel is just as durable in the water in this mine as wrought iron."

Says one of the largest coal operators in Kentucky:

> "We thought the data decidedly in favor of steel, in view of the fact that we had anticipated a reversal of the leaning * * * * The results of this investigation would appear to indicate no practical difference in the life to be obtained from either iron or steel piping in the hot water service."

This from a coal operator in Pennsylvania. Comparisons of new steel and iron pipes in the boiler feed and other lines led this large company, which made the test, to the exclusive use of "NATIONAL" Pipe.

> "While corrosion was about the same, there was a pitting in the iron that we did not find in the steel, and the steel was corroded more uniformly. From the tests made, I know that the steel pipe is the better for such conditions."

This conclusion from an operator in the largest bituminous coal field in the world indicates the advantages accruing to the uniform material of "NATIONAL" Pipe when worked by the Spellerizing process.

STOUGHTON—In the text book, "The Metallurgy of Iron and Steel" (Hill Publishing Co., New York), by Bradley Stoughton, who has carried out exhaustive investigations, says:

> "The evidence goes to show that properly made steel corrodes no more than wrought iron."

In summing up a paper[5] on the corrosion of iron and steel, Bradley Stoughton, secretary of the American Institute of Mining Engineers, makes the following significant statement:

> "No mention has been made here of the sometimes heated discussion that went on for several years in regard to the relative corrosion of wrought iron and steel, because it is my opinion, which I think is the same as that now held by many well informed authorities, that the difference between these classes of materials, if any, is very small, and is much less important than the effect of quality of manufacture. In other words, well-made steel, or well-made wrought iron, will resist rusting better than badly made material of its own or the other class, and the reason for this I have tried to point out in the preceding pages, at the same time endeavoring to show some of the precautions that it is possible for engineers, owners and builders to employ in order to secure less corrodible material for use in the erection of structures."

HOWE AND STOUGHTON—An investigation was made and the results arrived at were incorporated in a paper, "The Relative Corrosion of Steel and Wrought Iron Tubing"—H. M. Howe and Bradley Stoughton (Proceedings of the American Society for Testing Materials. Volume 8, 1908), read before the American Society for Testing Materials, which concluded with the following pertinent words:

> "This is all the evidence which we have found and received permission to cite, though we have asked manufacturers prominently and financially interested in showing that steel is worse than iron, to give the addresses of those who could give us evidence. **None of that which we have found, but have not yet received permission to cite, is unfavorable to steel."**

(See "NATIONAL" Bulletin No. 11.)

[5] "The Causes and Prevention of Corrosion of Iron and Steel"—The Engineering Magazine, July, 1911.

FRIEND—J. Newton Friend, in his recent book, "The Corrosion of Iron and Steel" (Longmans Green Co., 1911), states:

> "It would appear therefore that when everything is taken into consideration there is practically nothing to choose between wrought iron and steel as at present manufactured." (Page 286.) And finally concludes with these words: "These and many other instances might be cited as illustrating the fact that good steel corrodes at much the same rate as good wrought iron." (Page 288.)

SANG—A. Sang, in a thorough résumé of the question entitled, "The Corrosion of Iron and Steel" (McGraw Hill Book Co., New York, 1910), says:

> "Properly protected steel and iron rust to about the same extent, the steel doing so more uniformly," and adds, "The best quality of charcoal iron is practically as resistant as the best quality of steel used for similar purposes." (Page 49.)

In regard to pipe, Sang remarks:

> "The carefully acquired experience of the largest manufacturers of tubes in the world, which induced them recently to abandon the manufacture of wrought iron pipe, teaches that the use of steel in place of iron, at least in the United States, for the special purpose of tubing is to be preferred; the tendency of steel to pit is somewhat less than that of iron and it welds at the joint fully as well." (Page 73.)

(See "NATIONAL" Bulletin No. 4.)

WOOLSON—Prof. Ira H. Woolson (Engineering News, December 8, 1910) secured 89 samples of corroded pipe from seven bath houses in New York City. Seventeen of these samples proved to be wrought iron and the remainder steel. Prof. Woolson says:

> "In my judgment from the evidence collected there was absolutely no difference in the corrosion of the two classes of pipe; they appear to be equally susceptible to the attack."

This pipe was tested to destruction.

(See "NATIONAL" Bulletin No. 2.)

WALKER—Perhaps the most recent investigation reported is that of Dr. W. H. Walker (New England Water Works Association, March, 1912), of the Massachusetts Institute of Technology, who secured 64 samples of wrought iron and steel pipe in adjacent service. These samples had been in service from 2 to 17 years.

Dr. Walker reported that of the 64 samples secured 20 pairs favor steel, 18 iron, 9 show no difference in corrosion and 17 no corrosion at all. Dr. Walker says in this paper:

> "These results again demonstrate that taken on the average there is no difference in the corrosion of iron and steel pipe. Conversations held with engineers in charge of plants during this investigation confirm the statement already made that a pipe is frequently called steel when corrosion is found to be excessive, while it is set down as iron if it rusts but little."

(See "NATIONAL" Bulletin No. 10.)

BALL—P. DeC. Ball (Cold Storage and Ice Trade Journal), in a paper read before the American Society of Refrigerating Engineers, stated as follows:

> "From thirty-three years of personal observation, constructing, erecting and operating ice-making and refrigerating machines, absorption and compression types, and using iron pipes for the first fourteen years and iron and steel pipe for the next nineteen years, we are convinced that local conditions only govern the corrosion of pipes in refrigerating and ice-making machines, and that, chemically and mechanically, mild steel pipe meets the requirements of the refrigerating engineer in all respects, and better than any other pipe for the reason that it is superior in point of finish, strength, strength of seam and uniformity of material."

(See "NATIONAL" Bulletin No. 5.)

COSGROVE—"Wrought Pipe Drainage Systems"[6] by J. J. Cosgrove contains many significant statements relative to the value of steel pipe when compared with wrought iron. We quote as follows:

> Page 3—"Such progress has been made toward improving the temper and weld of pipe steel, * * * * that today wrought iron pipe can scarcely be distinguished from steel pipe, so far as the cutting, threading and splitting are concerned." * * * *
>
> Page 7—"So far as wrought iron and steel pipes are concerned there is no appreciable difference between their length of life under similar conditions of exposure to corrosion, and one can be accepted as equally good as the other." * * * *
>
> Page 9—"As wrought iron and steel pipes are practically the same, they will be considered in this work, together with all other pipes of whatever metal or alloy which are put together with screw joints, as wrought pipes."

WOODWORTH—Mr. H. A. Woodworth, M.E., associated with the Merchant's Heat and Light Company, of Indianapolis, Ind., who read a paper "District Heating Distribution Systems" before the Annual Meeting of the National District Heating Association (1914) held in Rochester, N. Y., in regard to the merits of wrought iron and steel pipe, states that:

> "The use of steel pipe is becoming more popular every day, due to the good results found from practical experience. The author recently took up some ten inch and twelve inch mains of steel pipe and laid 16 inch in their place, and was surprised to find that the removed pipe showed the original stamping of the manufacturers[7] after thirteen years of usage on a hot water heating system. * * * * The pipe was laid again on our steam lines, being insulated with sectional covering and tile, and we expect it to last 25 years longer." * * * *
>
> "Since steel pipe is equally as good as wrought iron, it certainly is not a good policy to pay the difference in price for the latter pipe. Many other instances of steel pipe's good qualities might be cited but the discussion will no doubt bring out some mighty interesting features along this line."

VINCENT—G. I. Vincent in a paper "Street Main Standards"[8] read before the Eighth Annual Convention of the American Gas Institute, October, 1913, presented a summary of standards, suggestions derived from the best practice, and recommendations from over 200 gas companies relative to the best materials for pipe manufactured for gas service. The following quotations from this paper indicate the majority expression in favor of mild steel pipe—"NATIONAL" Pipe:

> "STEEL OR WROUGHT IRON—* * The mild steel now being turned out by the tube mills is really the so-called wrought pipe, and an order for wrought pipe or black pipe will be filled with steel. The so-called genuine wrought iron pipe commands a premium of about fifteen per cent over steel. **Its additional value is not apparent. Spellerized steel pipe is probably as durable as the wrought iron.**"
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> * * * * * * * * * * * *
>
> "Sixty-four per cent of the companies specified steel pipe, thirty-six per cent specified wrought iron. As heretofore stated the advantages of wrought iron pipe as now rolled, over the mild steel pipe of the trade is not apparent. Wrought iron pipe of charcoal iron might be more durable than mild steel, but pipe is not manufactured of this material."
>
> * * * * * * * * * * * *

[6] Published by Standard Sanitary Mfg. Co., Pittsburgh, Pa.

[7] Investigation revealed the fact that the pipe in question was "NATIONAL" Pipe, made by National Tube Company.

[8] October, 1913, issue American Gas Institute News—Volume II, No. 7, pages 73-108.

SUMMARY

"This summary is prepared for convenience in reference. It gives each item and the suggested best practice. * * * *

"STEEL MATERIAL FOR STREET MAINS—LOW PRESSURES

Steel vs. Wrought Iron	Steel
Merchant or Full Weight	Full Weight
Size in Preference to Cast Iron	Less than 4" diameter
Life of Steel Mains Expected	No suggestion
Coating	None, except in bad soils

"STEEL MATERIAL—HIGH PRESSURE—PIPE LINE

Steel vs. Wrought Iron	Steel
Weight	Line Pipe
Coating	None, except in bad soils"

SHATTUCK—J. D. Shattuck in a paper "Welding of High Pressure Mains" read before the Ninth Annual Meeting of the American Gas Institute (1914) reported the results of some tests on strength of autogenous welded pipe joints made on wrought iron and steel pipe by the Engineering Department of Swarthmore College and stated:

> "This test shows that steel pipe is stronger and more *ductile* than wrought iron pipe."

DUNCAN—R. B. Duncan associated with the United Gas Improvement Company of Philadelphia, Pa., in a paper "Installation and Maintenance of Service" read before the Ninth Annual Meeting of the American Gas Institute, 1914, states:

> "Succeeding the old lead pipe of the early days of the gas industry, wrought iron pipe was used almost exclusively for service work, for many years. It was far superior to lead from the standpoint of rigidity, being less liable to trap, and then it was cheaper. In the early 90's, the steel industry began making steel pipe cheaper than wrought iron and ever since that time, the use of wrought iron has been gradually falling off. The first impression of steel pipe gained by engineers was far from good; it had the reputation of being very uncertain as to temper and weld. Many claimed that great difficulty was experienced in cutting threads and that split pipe very frequently occurred. The general opinion of engineers that steel pipe was markedly inferior to wrought iron in resistance of corrosion is one that has caused much discussion.
>
> "Year by year the steel industry perfected their product until the pipe became as soft as wrought iron with no more power needed to thread same than wrought iron. As to the question of the corrosion of steel pipe versus wrought iron it is a feature that has been discussed by many prominent metallurgists of the country. The consensus of opinion seems to be that there is practically no difference between the two on this point. There have been many tests made both in laboratory and field. The United Gas Improvement Company have made many such tests. From laboratory experience, as far back as 1905, it was decided that there was little difference between wrought iron and steel in reference to corrosion; in fact, it was discovered that the new steel pipe appeared to have an outer coating of oxide which would resist corrosion far better than wrought iron. Many tests have been made of actual conditions in the field, and it has been the general opinion that both kinds of pipe showed almost the same loss of weight by corrosion, the tendency toward pitting being somewhat less in steel.
>
> "The steel industry has been developing a new process which, after several years' time, has given many encouraging results. By this process the steel is treated mechanically and does not in any way depend upon skilled labor beyond keeping up the machinery involved, hence uniform treatment is assured.
>
> "This new process is a method of treating metal which consists in subjecting the heated bloom to the action of rolls having regularly shaped projections on their working surfaces, then subjecting the bloom, while still hot, to the action of smooth faced rolls and repeating the action whereby the surface of the metal is worked so as to produce a uniform dense texture better adapted to resist corrosion, especially in the form of pitting.
>
> "Summing up the comparison, I would say that the steel pipe had four points to its advantage, that would justify its use in preference to wrought iron, as follows:
>
> (1) It costs much less.
> (2) It is stronger and more ductile than wrought iron.
> (3) It is more uniform in composition.
> (4) The threads cut on steel pipe appear to be stronger."

The Gas Record [9] in publishing an abstract from Mr. Duncan's paper, states, in regard to the value of the Spellerizing process which is applied to "NATIONAL" Pipe only (sizes four inches and under) that:

> "The consensus of opinion is that modern steel pipe, particularly if Spellerized, is as durable as wrought iron, and is, besides, cheaper, stronger and more ductile and more uniform in composition."

SMITH—The unbiased opinion of a recognized authority on any certain subject has a definite and ascertainable value. The following quotation relative to the merits of the Spellerizing process is taken from a paper "Some Causes of Corrosion or Oxidation of Metals in a Refrigerating System" by Morgan B. Smith, published in "Ice", October, 1913.

> "Steel Pipe, which has been treated in such a manner as to eliminate or at least distribute evenly the mill scale, may be joined with wrought iron or cast iron safely as a rule. * * * * The same stock without the treatment for mill scale will show a decided tendency to corrode when joined with wrought iron or cast iron. The so-called Spellerized Steel fulfills this condition with respect to the scale."

SPELLER—F. N. Speller in summing up a series of articles on the relative durability of Wrought Iron and Steel Pipe under the heading "Plain Facts about 'NATIONAL' Pipe for the Plumber and Steamfitter" published in the Plumbers' Trade Journal, Dec. 15, 1913, [10] Jan. 1 [11] and 15 [12] and Feb. 1 [13] 1914, states:

> "It should be borne in mind by all thoughtful members of the trades handling pipe that:
>
> "1. Steel pipe is no longer an experiment, but has a record of 25 years' service—and in that time has increased in use to ninety per cent of the entire tubular production.
>
> "2. Opinions should be based on a real personal knowledge, taking nothing for granted—the average user of pipe has abundant opportunity to investigate for himself.
>
> "3. All the comparisons, which have been made in service covering the average life of pipe today, indicate clearly that there is no difference in life between iron and steel pipe as a class, although there is something to say between the various makes of each class.
>
> "4. All reputable makes of pipe are now marked so that substitution or mistakes are no longer possible. The fact that so much steel pipe has been used, supposedly as wrought iron, in the past is very significant in the light of real experience.
>
> "5. It is advisable to inquire carefully into the basis of statements made on the general question of iron and steel pipe—hearsay and supposition are dangerous substitutes for real experience in such matters."

[9] Page 222, Sept. 23, 1914, Vol. 6, No. 6.
[10] Pages 807-808.
[11] Pages 29-30.
[12] Pages 107-108.
[13] Pages 191-192.

IRON TRADE REVIEW—In a leading editorial The Iron Trade Review, October 15, 1914, page 699, comments upon the tremendous growth of the steel pipe industry in the past decade and gives statistics showing tonnages of both wrought iron and steel pipe for years 1905 to 1913, inclusive, as compiled by the Bureau of Statistics of the American Iron and Steel Institute, issued in a Special Statistical Bulletin No. 8, and in conclusion states:

> "The popularity of steel pipe is due to a number of causes. Undoubtedly, its economy has been an influential factor, but the great increase in production during the past two decades cannot be attributed to price alone. Quality also has played an important part. The uniform character of well-made steel pipe is a factor in its favor, and its ductility adds to its serviceableness. * * * *
>
> "As far as the subject of corrosion is concerned, without going into exhaustive arguments, it may be said that prominent metallurgists now agree that any special fears which may have been entertained regarding the resistance of steel pipe to corrosion are groundless. It seems, therefore, that there are sound economic reasons behind the tremendous increase in the production of steel pipe during the past 25 years."

PROOF OF "NATIONAL" PIPE SUPREMACY

THE illustrations in this "NATIONAL" Bulletin are from photographs of a few of the larger and more important financial, office, industrial and public buildings, containing "NATIONAL" Pipe, which are to be found in some of the principal cities of the United States. These alone will be sufficient evidence to satisfy the reader that "NATIONAL" Pipe has been and is being specified and used successfully in building construction of national importance.

It will be noted that practically all the buildings illustrated are of recent construction, proving the position now held by "NATIONAL" Pipe and Allied Products in the Architectural, Engineering and Industrial World; and in addition, that those interested in the erection of modern buildings value and have confidence in the service given by "NATIONAL" Pipe.

That "NATIONAL" Pipe has proved efficient, reliable and economical is evident from the importance of the buildings illustrated in this Bulletin, for each building contains "NATIONAL" Pipe in one or more of the principal systems of pipe installed for various purposes.

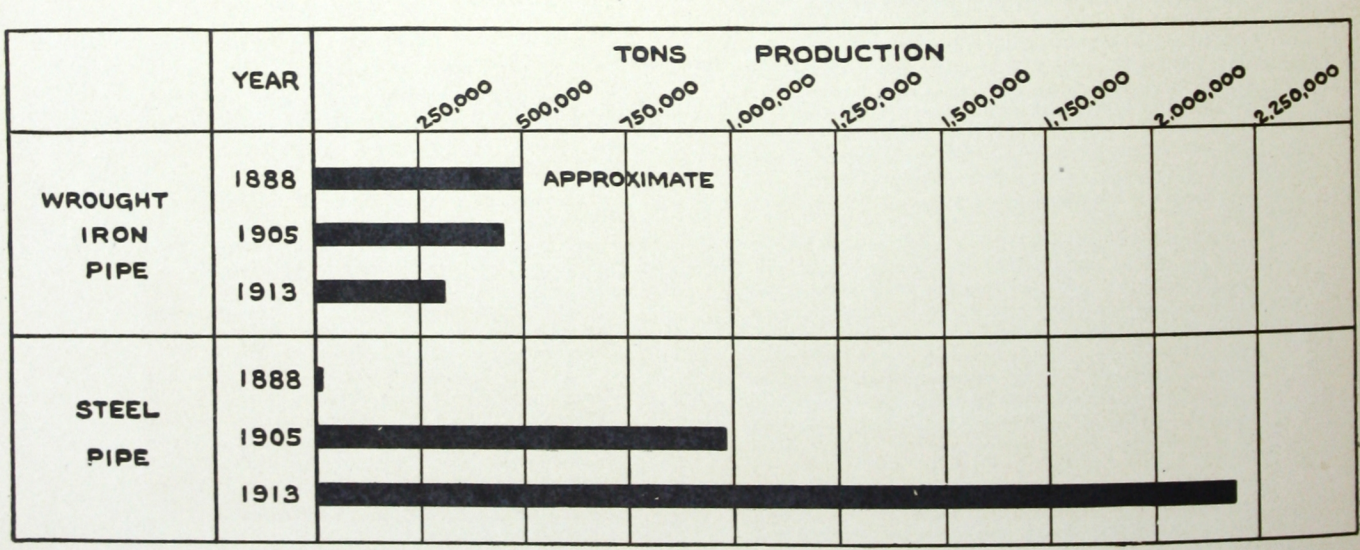
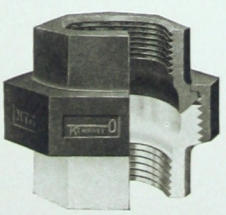


Diagram Showing Production of Wrought Iron and Steel Pipe from 1888 to 1913

OVER-SHADOWING SUPREMACY—WHAT DOES IT MEAN?

Just this—THE GRAND PRIZE (highest possible award—there was only **one** Grand Prize for each class of exhibits) was given by the Superior Jury of Awards to "NATIONAL" Tubular and Allied Products, including "NATIONAL" Pipe, "KEWANEE" Unions and Specialties, and "SHELBY" Seamless Steel Tubing, "as representing the highest development of the art."



GRADE OF MARKINGS FOR PRIZES AT THE PANAMA-PACIFIC INTERNATIONAL EXPOSITION.

The Grand Prize—Beyond Comparison

Medal of Honor, 95 to 100 Gold Medal, 85 to 94
Silver Medal, 75 to 84 Bronze Medal, 60 to 74
Honorable Mention (No Medal)

BANKS AND FINANCIAL OFFICE BUILDINGS

CONTINENTAL AND COMMERCIAL NATIONAL BANK BUILDING
Chicago, Ill.
Said to be the Largest Bank Building in the World

ARCHITECTS—D. H. Burnham & Company, Chicago, Ill.; Graham, Burnham & Company, Chicago, Ill.
PLUMBING CONTRACTOR—M. J. Corboy. HEATING CONTRACTORS—Hanley-Casey Company

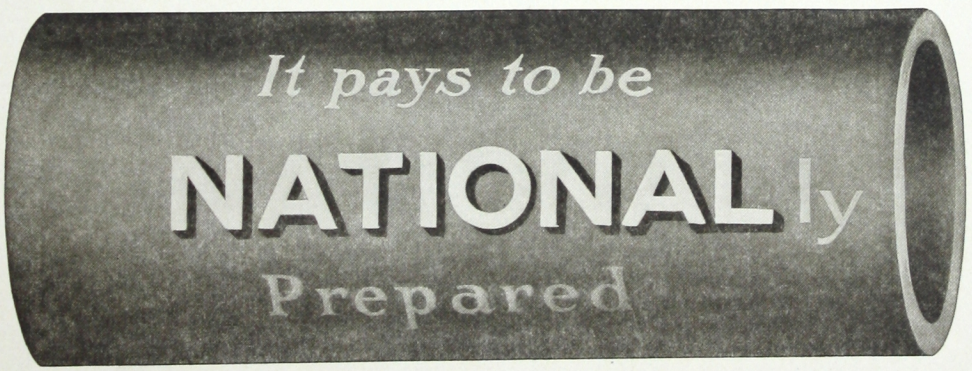
CONTINENTAL AND COMMERCIAL NATIONAL BANK BUILDING CHICAGO, ILL.

THE Continental and Commercial National Bank Building, Chicago, Illinois, is considered one of the largest banking or financial office buildings in the world. The Architectural Record, July, 1915, issue, reviewing the work of the late D. H. Burnham and his associates, states:

"This structure is of such magnitude that a brief description of its vast proportions and size may be found of some interest to the reader. It covers an entire city square in the center of the financial district of Chicago and is the largest Bank and Office building in that city. * * * * Its length from east to west is 325 feet and its width from north to south 116 feet. The main entrance is on LaSalle Street, through a loggia of immense polished granite columns, which envelop cores of steel, surrounded with concrete for fire proofing in case by any event the granite might be destroyed by a conflagration. A corridor through the center on the first floor extends to Fifth Avenue, where is another principal entrance. The main banking room occupies the entire second floor and is approached by two marble staircases in the center of this corridor, near each entrance. In some parts the banking room occupies the space of four stories in height above the ground floor. The rented office section is reached by four stacks of elevators and stairways, which penetrate through the banking room near the four corners of the building. * * *

"* * * * Attention may be called to the very interesting fact that the barrel vaulted skylight which illuminates the main banking room in the center is built under the great interior court. A view of the exterior from the southeast taken from the top of a building a block away makes an admirable reproduction, showing the monumental grandeur of the huge pile seen as a whole without distortion of its perspective lines. The exterior of the first three stories is of granite. Above this it is faced with enameled terra cotta of granite color.

"The upper part of the Continental and Commercial National Bank Building, built to the highest point ever authorized by law in Chicago, can be seen from a great distance, even over the tops of other 'skyscrapers', and is an important land mark in the city. * * * * Its exterior design was a matter of serious study by the architects. In this it will be seen how they have accentuated the vertical lines of shafts of the building contrary to the old method of introducing horizontal lines and masses or of treating the shaft as a uniform decorative surface no matter of how many stories it might happen to consist."



BROWNWOOD NATIONAL BANK BUILDING
Brownwood, Texas

ARCHITECTS—Sanquinet & Staats, Fort Worth, Texas
CONTRACTORS—Hood & Staggs, Brownwood, Texas

CITY NATIONAL BANK BUILDING
Omaha, Nebraska

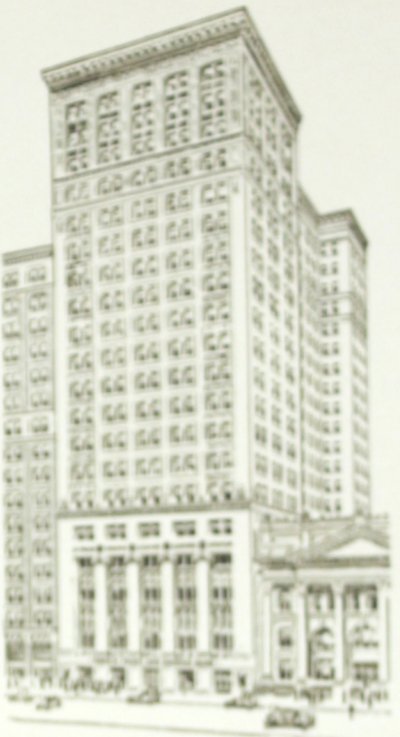
ARCHITECTS—Holabird & Roach, Chicago, Ill.
HEATING AND PLUMBING CONTRACTORS—Hanighan Plumbing and Heating Company, Omaha, Nebraska

THIRD NATIONAL BANK BUILDING
Atlanta, Ga.

HEARD NATIONAL BANK BUILDING
Jacksonville, Fla.

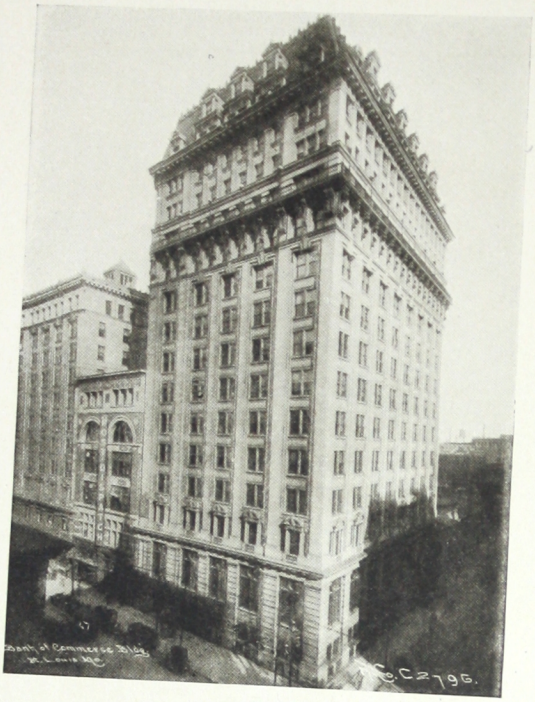
NATIONAL LOAN & EXCHANGE BUILDING
Columbia, S. C.

BANKER'S TRUST BUILDING
New York City
Architects—Trowbridge & Livingston, New York City
Heating Engineer—Henry C. Meyer, New York City
Heating Contractors—W. G. Cornell & Co., New York City
Plumbing Contractors—Gillis & Geoghegan, New York City



HARRIS TRUST COMPANY BUILDING
Chicago, Ill.
Architects—Coolidge & Hodgdon, Chicago, Ill.
Heating Contractors—Dixon Steam System Company
Plumbing Contractors—Hulbert & Dorsey Company

EDISON BUILDING
(Formerly The Commercial National Bank Building)
Chicago, Ill.



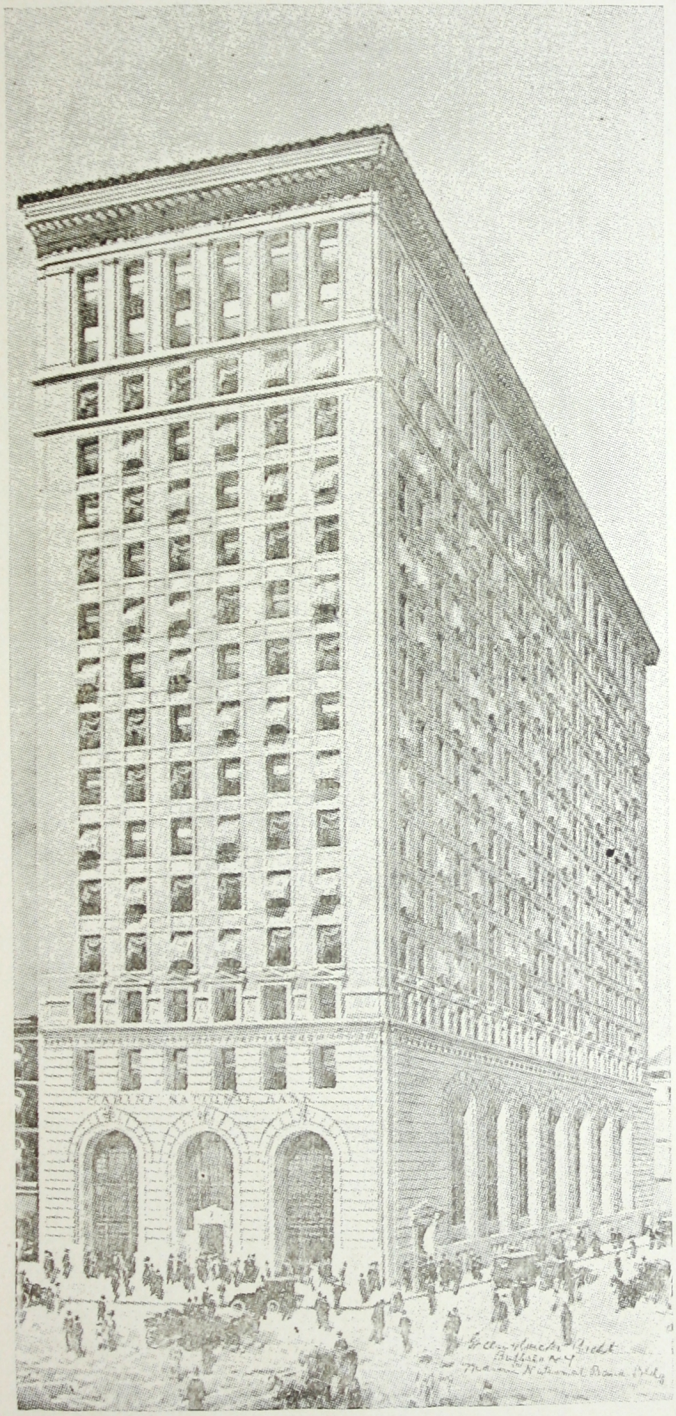
BANK OF COMMERCE BUILDING
St. Louis, Mo.
ARCHITECTS—Mauran, Russell & Garden
CONTRACTOR—James Stewart

AMERICAN BANK & EMPIRE BUILDING
Seattle, Washington

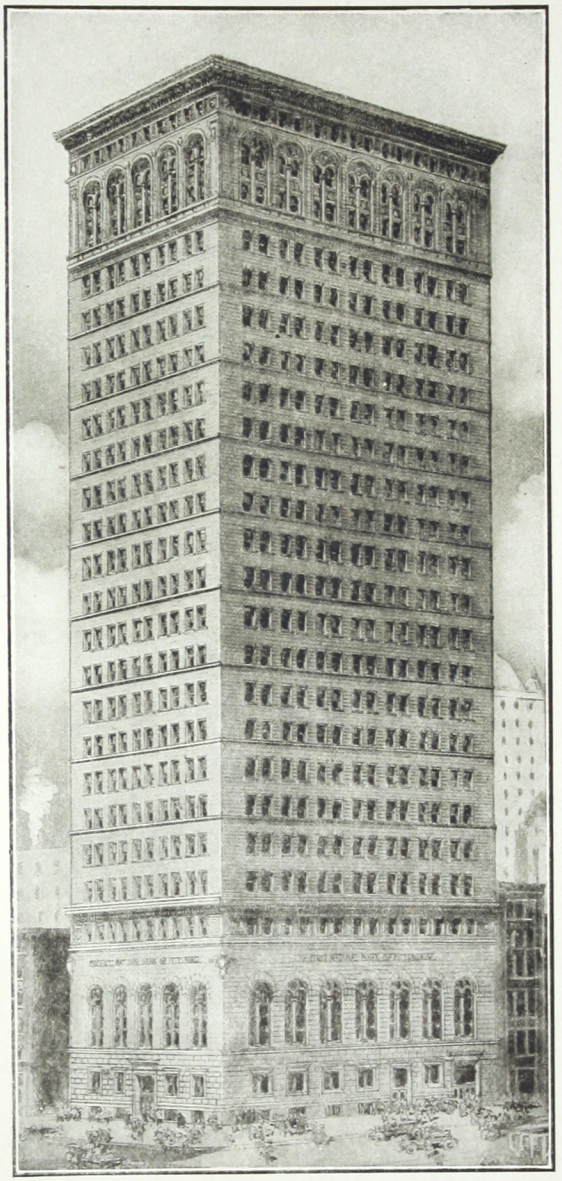
NORTHWESTERN BANK BUILDING
Portland, Ore.
ARCHITECTS—Doyle & Patterson
CONTRACTORS—Dinwiddie Construction Company

WALKER BANK BUILDING
Salt Lake City, Utah
ARCHITECTS—Eames & Young, St. Louis, Mo.
CONTRACTORS—James Black Masonry & Construction Company, St. Louis, Mo.

THIRD NATIONAL BANK BUILDING
St. Louis, Mo.
ARCHITECTS—Eames & Young, St. Louis, Mo.
CONTRACTOR—James Bright



MARINE NATIONAL BANK BUILDING
Buffalo, N. Y.
ARCHITECTS—Green & Wickes, Buffalo, N. Y.
CONTRACTORS—Wells & Newton Company, New York City



FIRST-SECOND NATIONAL BANK BUILDING
Pittsburgh, Pa.
ARCHITECTS—D. H. Burnham & Company, Chicago, Ill.

OLD NATIONAL BANK BUILDING
Spokane, Wash.
ARCHITECTS—D. H. Burnham & Company, Chicago Ill.

TITLE GUARANTEE & TRUST COMPANY BUILDING
St. Louis, Mo.
ARCHITECTS—Eames and Young, St. Louis, Mo.
CONTRACTORS—Griffiths & Wells, Chicago, Ill.

SYNDICATE TRUST BUILDING
St. Louis, Mo.
ARCHITECT—H. F. Roach
CONTRACTORS—Hill-O'Meara Construction Company

FIRST NATIONAL BANK BUILDING
Chicago, Ill.
ARCHITECTS—Graham, Burnham & Company, Chicago, Ill.

TRUST AND SAVINGS BUILDING
Los Angeles, Cal.

FIRST NATIONAL-SOO LINE BUILDING
Minneapolis, Minn.

MERCHANTS NATIONAL BANK BUILDING
St. Paul, Minn.

MERCHANTS NATIONAL BANK BUILDING
Boston, Mass.
Architects—Shepley, Rutan and Coolidge, Boston, Mass.
Contractors—Wells Brothers
Heating Contractors—Lynch and Woodward

OFFICE BUILDINGS

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EQUITABLE BUILDING
New York City
Said to be the Largest Office Building in the World

ARCHITECT—Ernest R. Graham, Chicago, Ill. CONTRACTORS—Thompson-Starrett Company, New York City
HEATING CONTRACTORS—Thompson-Starrett Company, New York City. PLUMBING CONTRACTORS—J. N. Knight & Son, New York City

EQUITABLE BUILDING
NEW YORK CITY

THE Equitable Building, New York City, recently completed, is the largest office building in the world. It is 38 stories high, will accommodate approximately 15,000 tenants, and contains the most efficient modern office building equipment.

"NATIONAL" Pipe has been installed throughout the heating and plumbing lines, with the exception of the hot water supply lines, which are brass. The total length of the "NATIONAL" Pipe lines approximates 235 miles, or about the distance from New York to Boston.

It will not be necessary to enlarge at length on the advantages of "NATIONAL" Pipe and Fittings, it will suffice to state this fact:

> Although almost 100,000 cast and malleable iron fittings and about 13,350 valves were installed in connecting a wide range of sizes of "NATIONAL" Pipe (all of which had to be cut, re-threaded and marked for a particular place in the building) yet NOT ONE SINGLE LENGTH OF "NATIONAL" PIPE WAS REJECTED ON ACCOUNT OF DEFECTIVE MATERIAL.

The heating system is designed to use the exhaust steam from the engines, turbines, pumps, etc., in the power plant, which is located 50 feet below the curb line and is so arranged that the exhaust steam flows directly into a 30 inch pipe line about 500 feet long and extends to the 34½ floor, where it supplies a trunk line ranging in size from 24 inch down to four inch "NATIONAL" Pipe. From this trunk line there are 66 risers which furnish steam to the thousands of radiators throughout the building. There are also 66 return risers which start with one inch and increase to two inch "NATIONAL" Pipe by the time the lower floor is reached.

In addition to the miles of "NATIONAL" Pipe used in the heating and other piping systems, "SHELBY" Hot Rolled Seamless Steel Boiler Tubes have been installed in the battery of seven large boilers which generate steam for the numerous engines and pumps required in the power plant.

The quantity of water indispensable to the requirements of a building of this magnitude is enormous, and it would seem certain that the plumbing systems of the Equitable Building, which furnish successfully an adequate water supply, fulfill the highest ideals of modern plumbing engineering in design, equipment and materials.

The water supply is obtained at six different points, through four six inch and two four inch mains, under an average pressure of 35 pounds per square inch. The water, after being filtered through five 90 inch filters, each with a filtering capacity of 10,000 gallons per hour, flows into large surge tanks from which it is pumped throughout the building.

The height of the building and consequent long pipe lines inevitably cause pipe friction and loss of heat, thus necessitating a division of the hot and cold water supply systems into four units, each a complete and self-contained system.

The first unit, known as the "street level", supplies the street floor, basement and sub-basements. The second unit, known as the "low level", supplies the floors from the street to the 16th floor from two 500 gallon tanks located on the 16th floor. From this floor a trunk line, supplying cold water to the lower floors, is carried to the ceiling of the 15th floor, where it is sub-divided into 36 risers, beginning with four inch "NATIONAL" Pipe and reducing to three-quarter inch at the first floor. The third unit is supplied from tanks located on the 26th floor. The fourth unit, known as the "high level", is supplied from tanks located on the 38th floor and supplies the remaining floors, down to the 26th floor. The two tanks located on the highest level have a total capacity of 25,000 gallons, and from these tanks four fire protection system lines are laid to strategic points in the building. And all these lines it will be remembered are "NATIONAL" Pipe.

In case of fire on any floor, one quarter of the building, including the section on fire, can be closed off with fire-proof doors, leaving the remainder of the building free and open for egress of tenants.

The hot water supply system is similar in design to that of the cold water supply, and contains eight hot water heaters supplying the entire building. Each system has a delivery capacity of 500 gallons per hour, and a heating capacity of 2000 gallons per hour, with a temperature ranging from 50 to 180 degrees Fahr. at atmospheric pressure. The hot water is tapped from tanks located on the several different "levels", and is piped to the various risers from whence it flows to the basins and sinks on each floor. From the highest point on each hot water supply riser, there is an extension pipe fitted with an air cock; this pipe runs to the top of the supply tank and allows the escape of any confined or excess air that might accumulate in the system. (See "The Design of Hot-water Supply Systems to Minimize Corrosion" by F. N. Speller, Metallurgical Engineer, National Tube Company, published in Engineering News, February 13, 1913, and reprinted on pages 54 and 55 of this Bulletin.)

Throughout the piping systems described above, the pipe used is "NATIONAL" Galvanized Pipe, sizes one-eighth inch to twelve inches, and includes 143 risers for cold water, gas, waste and vent lines. The various lines were tested hydrostatically with pressures ranging from 100 to 500 pounds per square inch prior to being accepted as complete and ready for use.

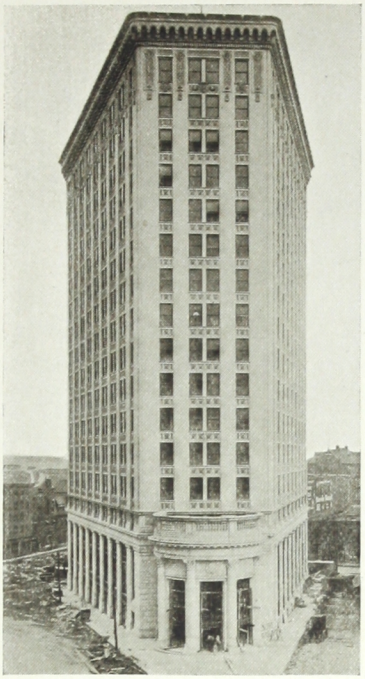
HEALY BUILDING
Atlanta, Ga.
HEATING CONTRACTOR—M. C. Vandever

CONWAY BUILDING
Chicago, Ill.
ARCHITECTS—Graham, Burnham & Company, Chicago, Ill.
D. H. Burnham & Company, Chicago, Ill.
PLUMBING CONTRACTOR—R. J. Powers

KARPEN BUILDING
Chicago, Ill.

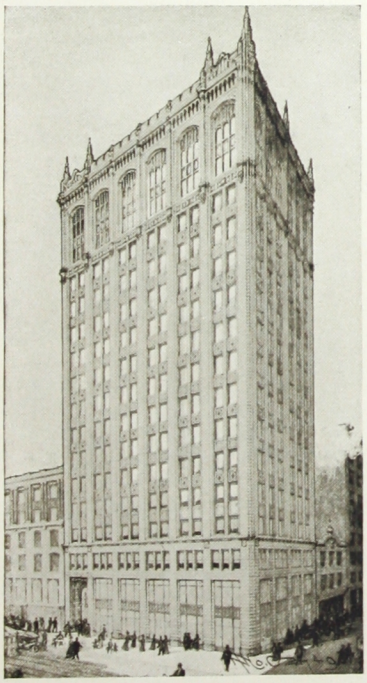
HOLLINGSWORTH BUILDING
Los Angeles, Cal.
ARCHITECTS—Morgan, Wall & Morgan, Los Angeles, Cal.
HEATING CONTRACTORS—American Heating & Construction Company
PLUMBING CONTRACTORS—Howe Brothers

CANDLER BUILDING
Atlanta, Ga.
ARCHITECT—George W. Murphy

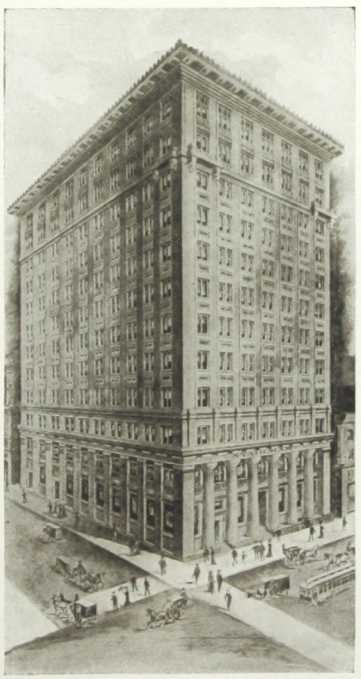


HURT BUILDING
Atlanta, Ga.

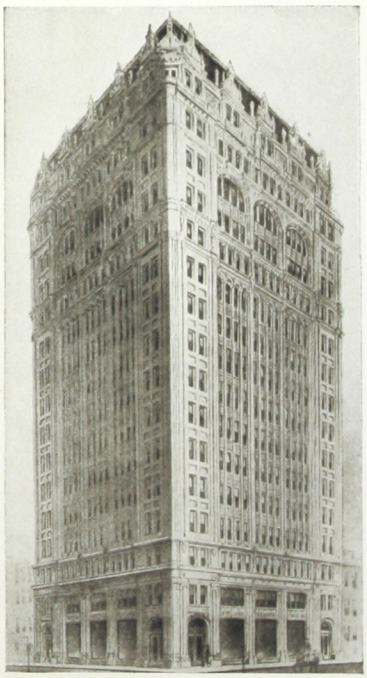
RAILWAY EXCHANGE BUILDING
Chicago, Ill.
ARCHITECTS—Graham, Burnham & Company
Chicago, Ill.



STATE BUILDING
Chicago, Ill.
ARCHITECT—Jas. B. Dibelka, Chicago, Ill.
PLUMBING CONTRACTOR—M. J. Corboy



STAHLMAN BUILDING
Nashville, Tenn.



EMMET BUILDING
New York City
ARCHITECTS—Barney & Colt, New York City
CONSULTING ENGINEERS—Pattison Brothers
New York City
HEATING CONTRACTORS—Osborne, Rea & Company
New York City

THE ARCHITECTS BUILDING
New York City
ARCHITECTS—LaFarge & Morris; Ewing & Chappell, New York City
PLUMBING CONTRACTORS—W. G. Cornell & Company, New York City
HEATING CONTRACTORS—Mulhern Steam Heating Company
New York City

WHITEHALL BUILDING
New York City
ARCHITECTS—Clinton & Russell, New York City
HEATING CONTRACTORS—Child and Scott, New York City

UNION PACIFIC BUILDING
Omaha, Neb.
ARCHITECTS—Holabird & Roach, Chicago, Ill.
HEATING AND PLUMBING CONTRACTORS—Hanighan Plumbing & Heating Company, Omaha, Neb.

PENN MUTUAL LIFE INSURANCE COMPANY BUILDING
Philadelphia, Pa.
ARCHITECT—Edgar V. Seeler, Philadelphia, Pa.
CONSULTING ENGINEER—Henry Adams, Philadelphia, Pa.
CONTRACTORS—Doyle & Company, Philadelphia, Pa.
HEATING CONTRACTOR—W. M. Anderson, Philadelphia, Pa.
PLUMBING CONTRACTORS—Hoben & Doyle, Philadelphia, Pa.

WOODMEN OF THE WORLD BUILDING
Omaha, Neb.
ARCHITECTS—Holabird & Roach, Chicago, Ill.
HEATING AND PLUMBING CONTRACTORS—
Hanighan Plumbing & Heating Company
Omaha, Neb.

TELEPHONE BUILDING
Portland, Ore.

JOURNAL BUILDING
Portland, Ore.
ARCHITECTS—Reed Brothers
San Francisco, Cal.

PHILADELPHIA STOCK EXCHANGE BUILDING
Philadelphia, Pa.
ARCHITECT—HORACE Trumbauer, Philadelphia, Pa.
CONTRACTOR—Payne & Company
HEATING CONTRACTORS—S. Faith & Company
PLUMBING CONTRACTORS—Newel Brothers

SCARRITT BUILDING
Kansas City, Mo.
ARCHITECTS—Root & Siemens, Kansas City, Mo.
HEATING CONTRACTORS—Lewis & Kitchen, Kansas City, Mo.
PLUMBING CONTRACTORS—E. D. Hornbrook & Company
Kansas City, Mo.

PITTOCK BLOCK
Portland, Ore.

ARCHITECTS—Doyle & Patterson
CONTRACTORS—Brayton Construction Company

SELLING BUILDING
Portland, Ore.

ARCHITECTS—Doyle & Patterson
CONTRACTORS—James Stewart & Company

WILCOX BUILDING
Portland, Ore.

ARCHITECTS—Whidden & Lewis
CONTRACTORS—Brayton Engineering Company

WATTS BUILDING
San Diego, Cal.

PIERCE BUILDING
St. Louis, Mo.

ARCHITECT—Frederick C. Bonsack
CONTRACTORS—C. L. Gray Construction Company

RAILWAY EXCHANGE BUILDING
St. Louis, Mo.

ARCHITECTS—Mauran, Russell & Crowell
CONTRACTORS—Westlake Construction Company

TIMES BUILDING
St. Louis, Mo.

ARCHITECT—H. F. Roach
CONTRACTORS—W. Russ. Samuel Construction Company

ALASKA BUILDING
Seattle, Wash.

COBB BUILDING
Seattle, Wash.

STUART BUILDING
Seattle, Wash.

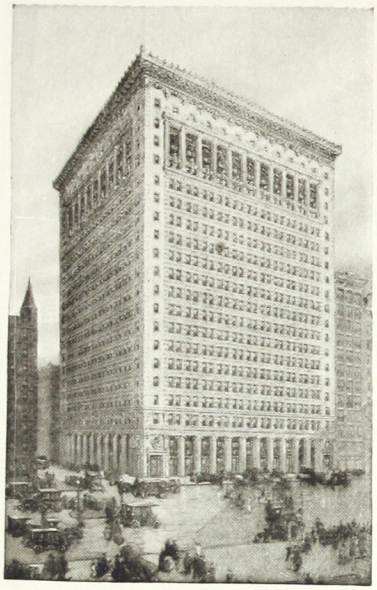
WHITE & HENRY BUILDINGS
Seattle, Wash.

COMMERCE BUILDING
Kansas City, Mo.

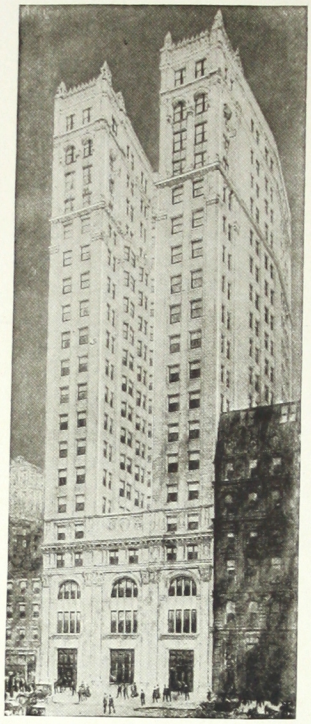
ARCHITECT—Jarvis Hunt, Chicago, Ill.
HEATING AND PLUMBING CONTRACTORS—E. D. Hornbrook & Co., Kansas City, Mo.

RIALTO BUILDING
Kansas City, Mo.

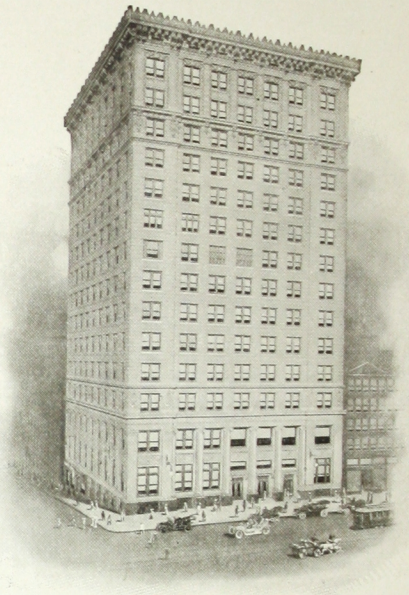
ARCHITECTS—Smith, Rea & Lovitt, Kansas City, Mo. CONTRACTORS—George L. Brown & Son, Kansas City, Mo.
HEATING CONTRACTORS—Lewis & Kitchen, Kansas City, Mo. PLUMBING CONTRACTOR—M. P. Conner, Kansas City, Mo.



PEOPLES GAS BUILDING
Chicago, Ill.
ARCHITECTS—Graham, Burnham & Company
Chicago, Ill.



FIFTY BROAD STREET BUILDING
New York City
ARCHITECTS—Shape & Bready, New York City
SANITARY ENGINEER—William C. Tucker
New York City
PLUMBING CONTRACTORS—E. J. McCabe
Company, New York City



R. A. LONG BUILDING
Kansas City, Mo.
ARCHITECT—Henry F. Holt, Kansas City, Mo.
HEATING AND PLUMBING CONTRACTOR—L. H.
Prentice, Chicago, Ill.

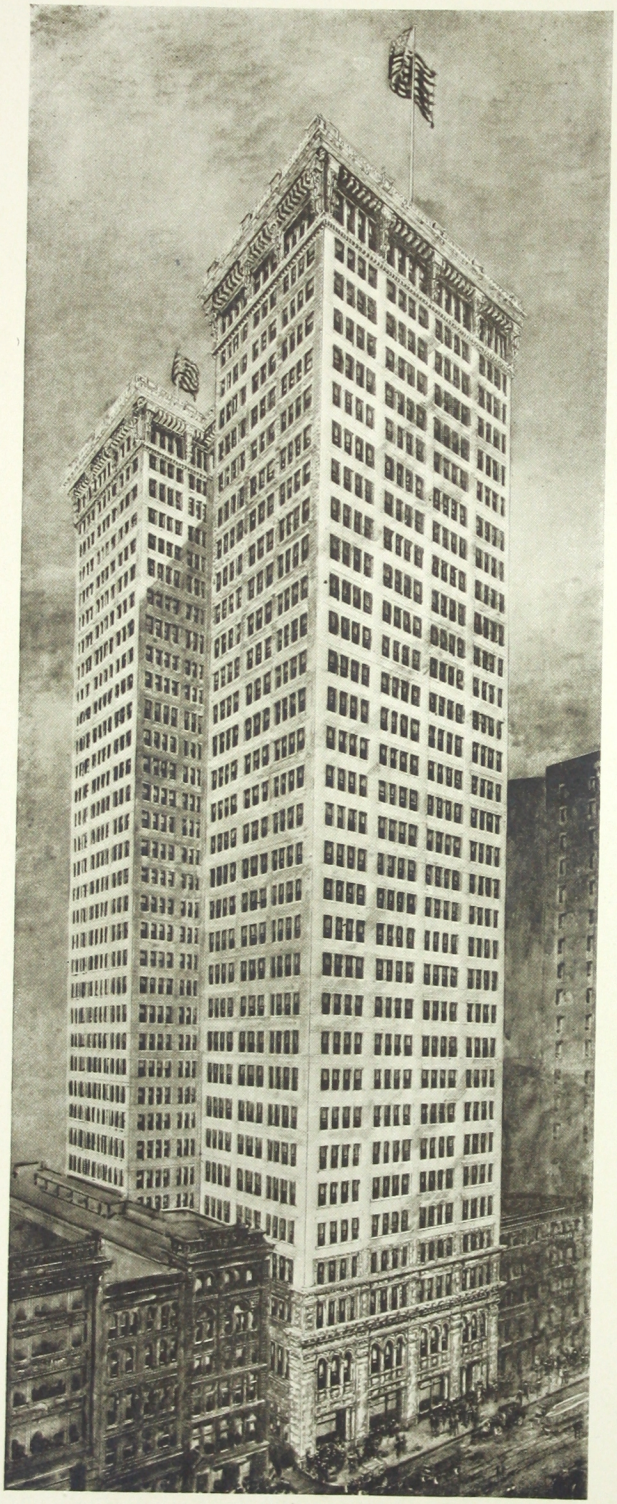
H. J. HEINZ COMPANY OFFICE BUILDING
Pittsburgh, Pa

HUDSON TERMINAL BUILDINGS
New York City
ARCHITECTS—Clinton & Russell, New York City

FIFTH AVENUE BUILDING
New York City
ARCHITECTS—Maynicke & Franks, New York City. CONSULTING ENGINEERS—Pattison Brothers, New York City
CONTRACTORS—Thompson-Starrett Company, New York City

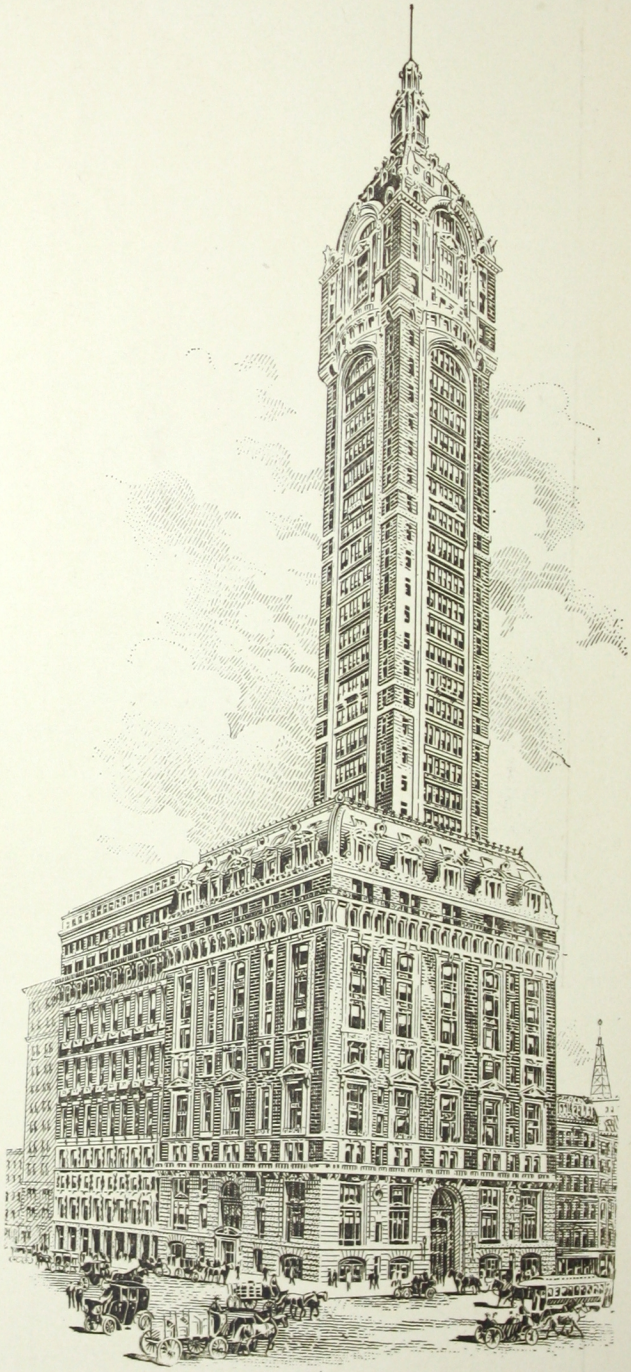
ST. JAMES BUILDING
Jacksonville, Fla.

TIMKIN BUILDING
San Diego, Cal.



ADAMS BUILDING
New York City

ARCHITECT—Francis H. Kimball, New York City
SANITARY ENGINEER—William C. Tucker, New York City
PLUMBING CONTRACTORS—James N. Knight & Son
New York City



SINGER BUILDING
New York City

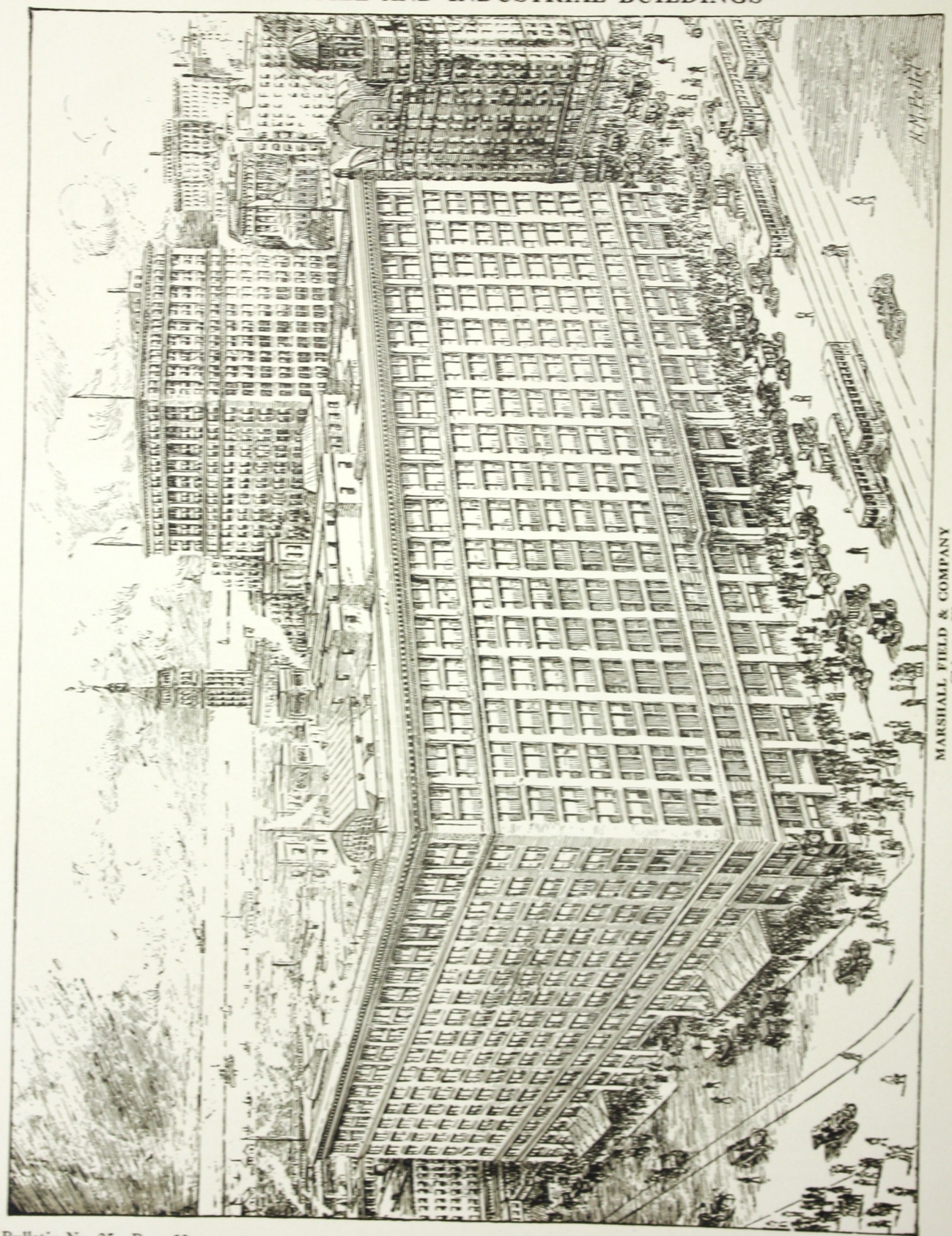
ARCHITECT—Ernest Flagg, New York City
HEATING CONTRACTORS—Child & Scott, New York City

VANADIUM BUILDING
Pittsburgh, Pa.
ARCHITECTS—S. Diescher & Sons, Pittsburgh, Pa.

RAILROAD BUILDING
St. Paul, Minn.
ARCHITECT—Charles S. Frost, Chicago, Ill.
STRUCTURAL ENGINEER—Max Toltz, St. Paul, Minn.
CONTRACTORS—Grant Smith & Company, St. Paul, Minn.

SAN MARCOS BUILDING
Santa Barbara, Cal.

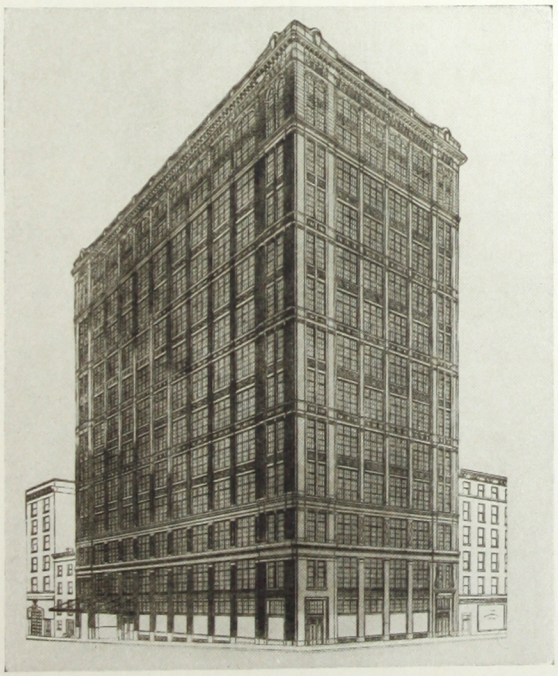
MERCANTILE AND INDUSTRIAL BUILDINGS



MARSHALL FIELD & COMPANY
Chicago, Ill.
Said to be the Largest Department Store Building in the World
ARCHITECTS—D. H. Burnham & Company, Chicago, Ill.; Graham, Burnham & Company, Chicago, Ill.
HEATING CONTRACTORS—Dixon Steam System Company. PLUMBING CONTRACTOR—R. J. Power.

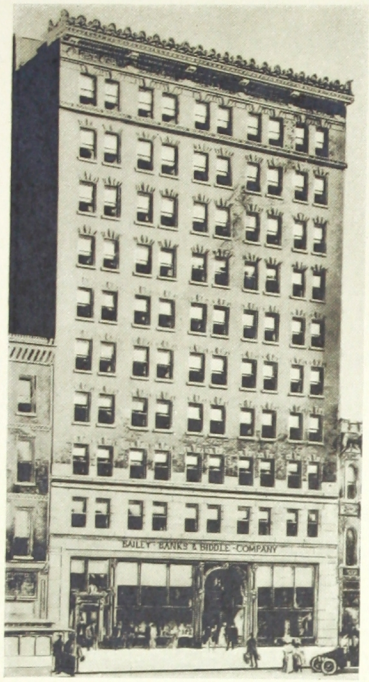
R. H. STERNS & COMPANY
Boston, Mass.
ARCHITECTS—Densmore & LeClear, Boston, Mass.

VAN NUYS BUILDING
Los Angeles, Cal.
ARCHITECTS—Morgan, Wall & Morgan, Los Angeles, Cal.
PLUMBING CONTRACTORS—Blumve & Jay Company



HILL BUILDING
New York City
ARCHITECTS—Starrett & Van Vleck, New York City
HEATING CONTRACTORS—Child & Scott, New York City
PLUMBING CONTRACTORS—W. G. Cornell & Company
New York City

HOLTZ STORE
Portland, Ore.
ARCHITECTS—Doyle, Patterson & Beach
CONTRACTORS—Brayton Engineering Company



BAILEY, BANKS & BIDDLE COMPANY
Philadelphia, Pa.

ARCHITECT—Goldwin Starrett
HEATING CONTRACTORS—Thompson-Starrett Company, New York City

JOHN WANAMAKER COMPANY
Philadelphia, Pa.

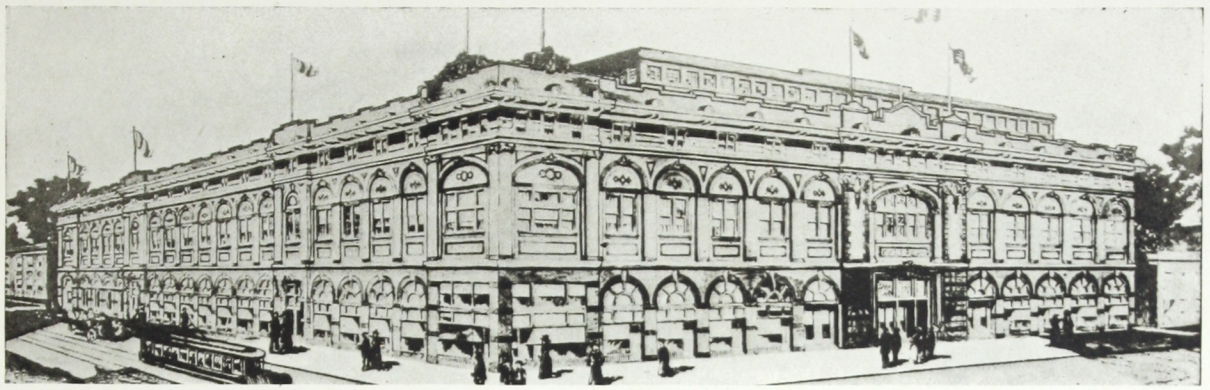
ARCHITECTS—D. H. Burnham & Company, Chicago, Ill.
CONTRACTORS—Burnham Company
HEATING CONTRACTOR—George Dickson
PLUMBING CONTRACTOR—William McCoach

LIPMAN WOLFE BUILDING
Portland, Ore.

ARCHITECTS—Doyle & Patterson
CONTRACTORS—Hurley Mason Company

LORD & TAYLOR
New York City

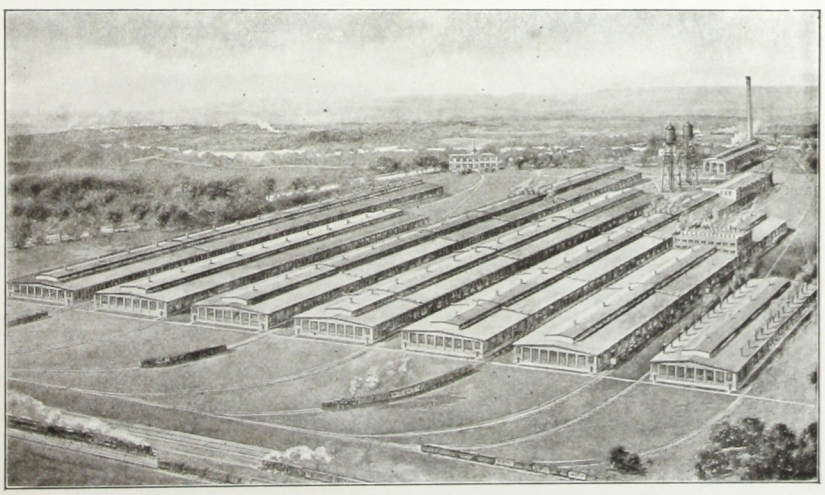
ARCHITECTS—Starrett & Van Vleck, New York City
HEATING ENGINEER—Edward Ashley, Jr., New York City
HEATING CONTRACTORS—Child & Scott, New York City



COLISEUM AND STORE BUILDING
St. Louis, Mo.
ARCHITECT—Frederick C. Bonsack, St. Louis, Mo. CONTRACTORS—C. L. Gray Construction Company

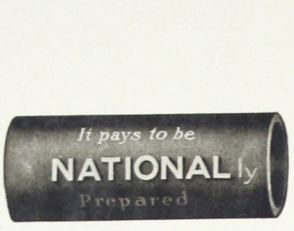
BUTLER BROTHERS
Dallas, Texas
ARCHITECTS—Mauran, Russell & Crowell, St. Louis, Mo.
CONTRACTORS—Selden-Breck Construction Company
St. Louis, Mo.

ARCADE BUILDING
Seattle, Wash.



H. W. JOHNS-MANVILLE COMPANY
Manville, N. J.
SPRINKLER SYSTEM CONTRACTORS—General Fire Extinguisher Company
New York City

THE TEXAS COMPANY BUILDING
Houston, Texas
ARCHITECTS—Warren & Wetmore, New York City
CONTRACTORS—George A. Fuller Constructing Company, Chicago, Ill.

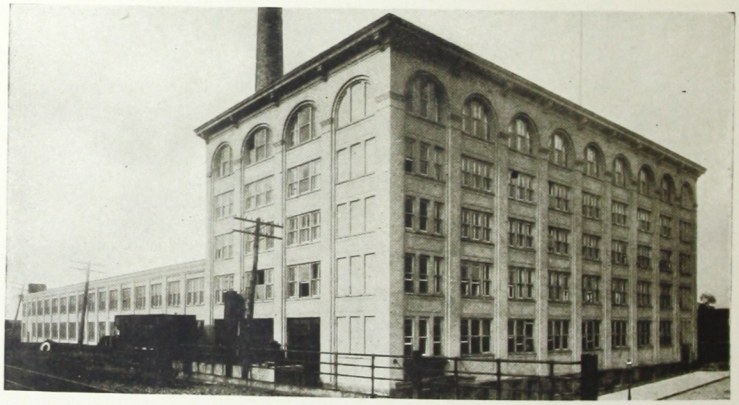


THE ALLING & CORY COMPANY
Pittsburgh, Pa.

ARCHITECTS—Hunting & Davis, Pittsburgh, Pa.
HEATING CONTRACTORS—Iron City Heating Company
Pittsburgh, Pa.
PLUMBING CONTRACTORS—W. N. Sauer, Pittsburgh, Pa.

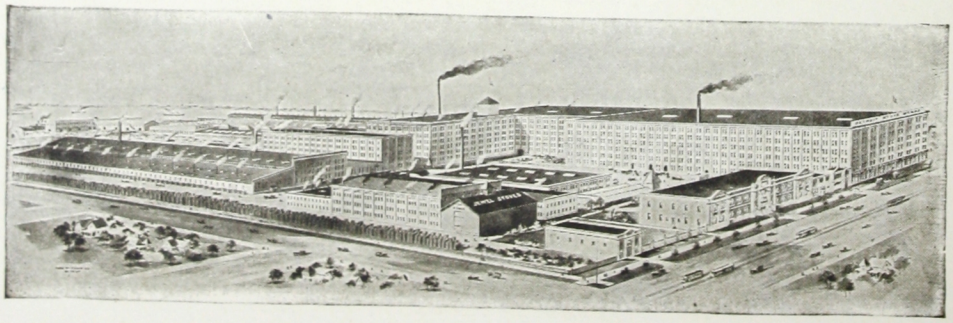
MUIR & FRANK
Portland, Ore.

ARCHITECTS—Doyle & Patterson
CONTRACTORS—Dinwiddie Construction
Company



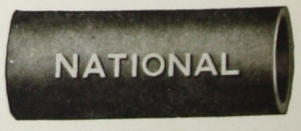
WARD & WARD, Inc.
Buffalo, N. Y.

ARCHITECT—C. B. Comstock, New York City
HEATING CONTRACTORS—E. Rutzler Company, New York City

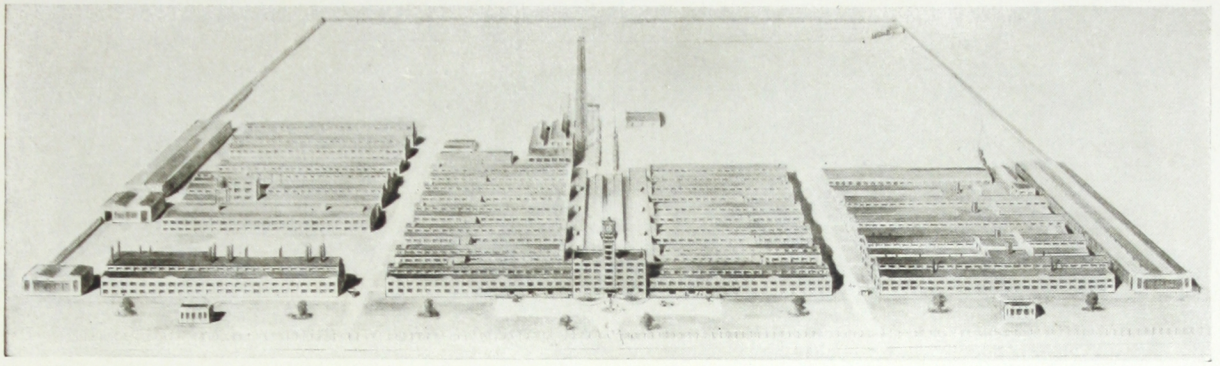


DETROIT STOVE WORKS
Detroit, Mich.

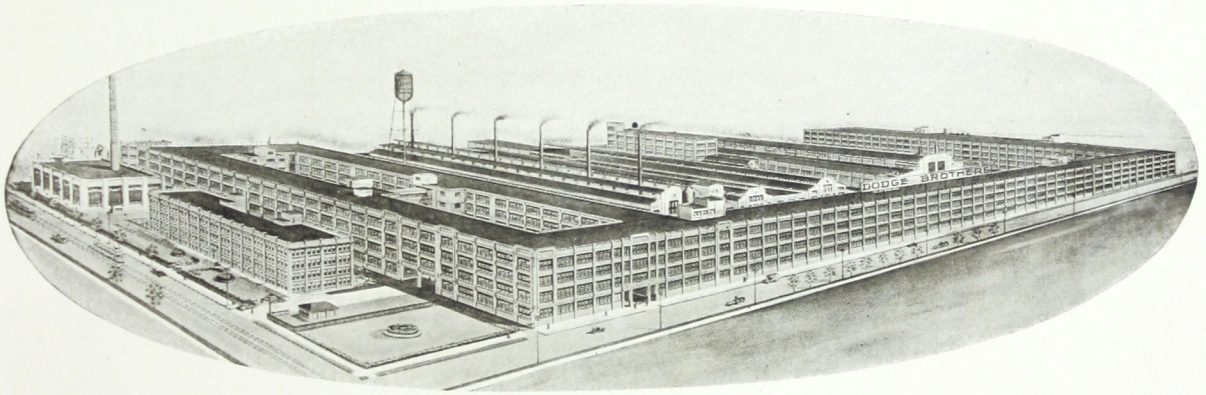
MARKING



Name Rolled in Raised Letters on National Tube Company Pipe



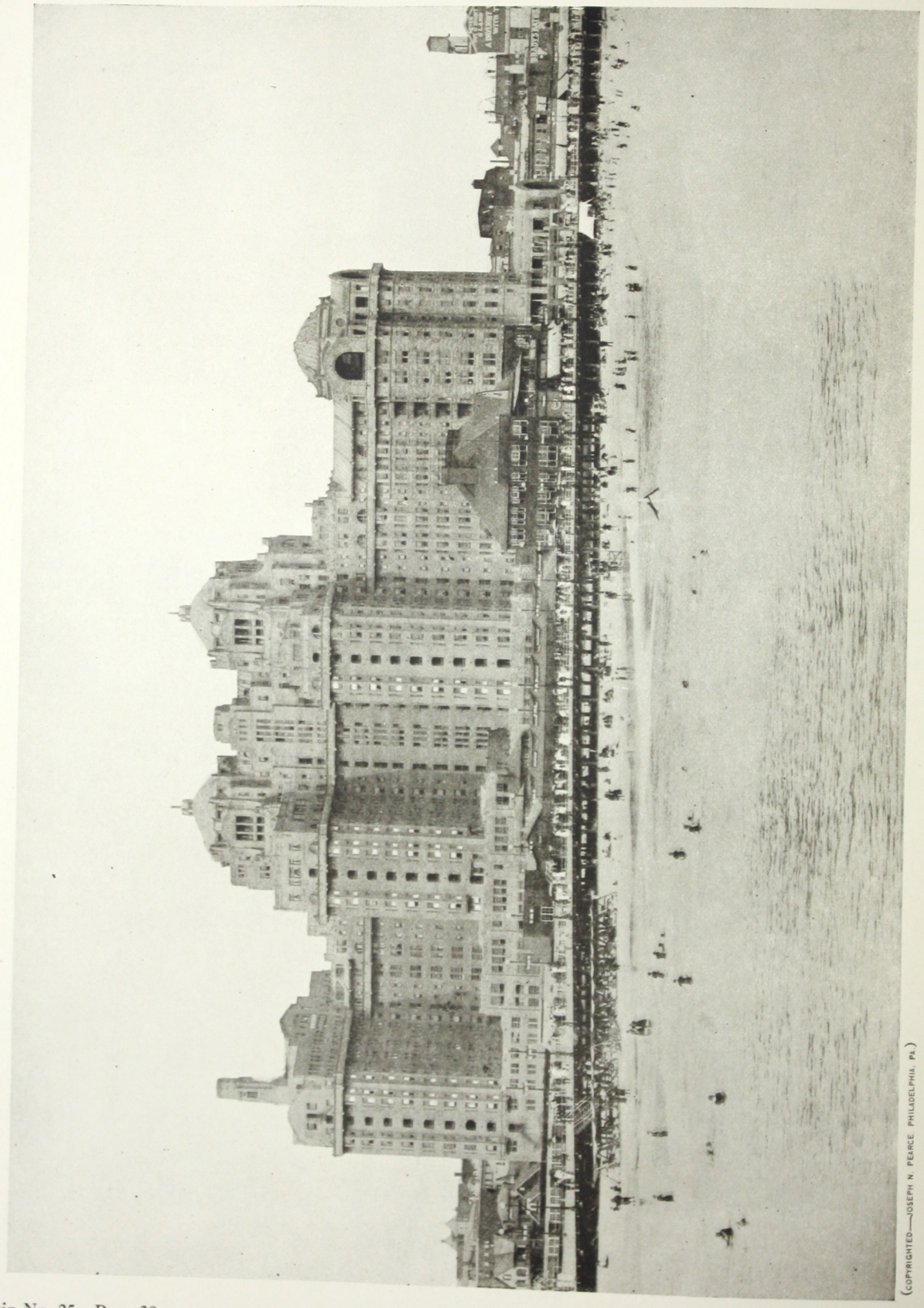
CRANE COMPANY
Chicago, Ill.



DODGE BROTHERS MOTOR CAR COMPANY
Detroit Michigan

MONTGOMERY WARD & COMPANY
Kansas City Mo.

HOTELS, CLUBS, APARTMENTS AND SIMILAR BUILDINGS



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HOTEL TRAYMORE
Atlantic City, N. J.
Said to be the Largest Resort Hotel in the World

ARCHITECTS—Price and McLanahan, Philadelphia, Pa.
STRUCTURAL ENGINEERS—Otto H. Gentner, Jr., F. Dickson Shaw, Associated Consulting Engineers, Philadelphia, Pa.
CONTRACTORS—Cramp & Company, Philadelphia, Pa. HEATING AND PLUMBING CONTRACTOR—William Anderson, Philadelphia, Pa.

HOTEL TRAYMORE
ATLANTIC CITY, N. J.

WHAT better proof can be cited of the recognized value of "NATIONAL" Pipe in the Architectural and Engineering world than the installations in the largest modern buildings?

"NATIONAL" Pipe has been installed in the new Hotel Traymore, Atlantic City, N. J., which is one of the largest "resort" hotels in the world. Some idea of its size may be indicated by a few facts. For instance: 2200 persons may dine at one time, and there are accommodations for 1400 guests and an army of employes. The building covers a city block, rising to a height of seventeen stories above the ground; is 150 feet wide, 500 feet long and 200 feet high. Within are the latest furnishings, decorations, luxuries and many novel features not found elsewhere, and in all, the cost amounted to $2,500,000.00!

From an Architectural and Engineering standpoint, the Hotel Traymore represents the acme of hotel design and construction, and as a whole is a remarkable achievement—not the least being the rapidity of erection—it was finished in about nine months!

The structure is steel, reinforced concrete and brick, with a facing of the latter combined with ornamental terra cotta. The Public Ledger, of Philadelphia, Pa., (May 30, 1915, page 5) in an article descriptive of the Hotel Traymore states:

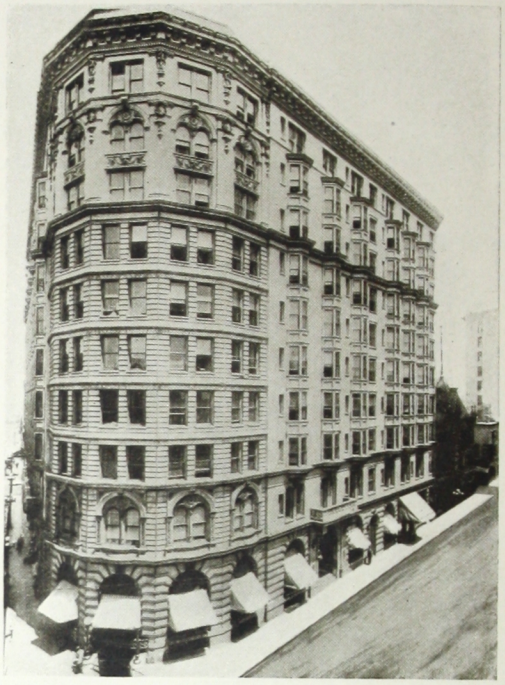
> "The Traymore is a veritable mountain, with shaggy, craggy peaks, pierced by precipices and canyons reaching to the Boardwalk. The skyline of America's playground is dominated by The Traymore, the ponderous golden domes glistening by day in the sunlight and studded by hundreds of electric lights by night.
>
> "All the wizardry of architecture, engineering and the builder's art is represented. In luxuries the new caravansary revels. The most demanding guest may be satisfied; the lowliest pocketbook may be accommodated.
>
> "* * * * Throughout the decorative scheme is symbolic of the ocean, ultramarine blue, sea green and sand hues standing out in an entrancing symphony.
>
> "A giant aquarium, visible from many floors and forming the ceiling of a grille, is the feature of all features. A fountain plays in the aquarium, stocked with hundreds of varieties of fish, that dart through the water, as sprays fall flashing over multicolored incandescent bulbs.
>
> "In the basement, built on sea level, is a sunken dance floor, above which also spreads the glass bottom of the pool above. The submarine floor also contains the European kitchen, the lavatories and the mechanical and refrigeration plants. The 'submarine' café has a seating capacity for 200.
>
> "The exchange floor opens from the Boardwalk. It measures 50 by 200 feet. On this floor is the American dining room, 80 by 125 feet, with a barrel-vaulted ceiling and decorative skylight, and the café. The latter is provided with a spacious balcony, which overlooks the main dining room. The office, waiting and writing rooms and a bakery complete this floor. It is in the exchange that guests are confronted with the glass enclosed fountain.
>
> "The mezzanine floor, reached from the main exchange by marble stairways, is taken up by the music room and promenade corridors. It is beautifully decorated and has a central decorative feature in the electrical fountain. From one of these corridors is visible through a glass partition the American kitchen.
>
> "With the 'submarine' café, two great dining rooms and four banquet halls, the Traymore is capable of seating 2200 persons at one time. The American dining room alone, will seat 700, and the European dining room 500. The largest of the banquet halls will provide for 400. Others will seat from 250 to 150 diners. Two hundred may find seats at tables in the 'submarine' café.
>
> "A summer dance hall is provided on the 11th floor, where swept by ocean breezes, it is described as the 'coolest spot' on the beach. There are 700 rooms and an equal number of baths, each the height of modern comfort. There are dormitory quarters for 600 employes, while an extra number may be cared for in a pinch.
>
> "When the house is fully furnished the payroll will have 1000 persons, 400 of whom will be waiters. A maitre d'hotel, taken from one of New York's finest hotels, will have under his direction six chefs and 200 kitchen workers.
>
> "With the exception of the sewage service, this 1915 model hotel is independent of public utilities. In the basement is a powerful plant for generating electricity for light and power and running a great refrigerating system, ample in its capacity to feed electricity to a large sized city. Water will be obtained from two artesian wells, each driven more than 800 feet deep. Their combined pumping capacity is 800 gallons a minute.
>
> "Ten plunger elevators, supported upon columns of water running down into the earth 200 feet and acting as cushions, are provided for the guests exclusively. There are others for baggage and employes.
>
> "In all details the requirements of such a vast hotel have been studied carefully. * * * *
>
> "The Traymore is declared to be fireproof, the result of many months of experiment on materials in laboratories. Every precaution to safeguard the guests has been observed."

MARKING

Name Rolled in Raised Letters on National Tube Company Pipe

ANSLEY HOTEL
Atlanta, Ga.

HEATING AND PLUMBING CONTRACTORS—Farrell Heating & Plumbing Company



PIEDMONT HOTEL
Atlanta, Ga.

HOTEL BURBRIDGE
Jacksonville, Fla.

HOTEL SEMINOLE
Jacksonville, Fla.

MASON HOTEL
Jacksonville, Fla.

ST. REGIS HOTEL
Kansas City, Mo.

HERMITAGE HOTEL
Nashville, Tenn.

MINNEAPOLIS ATHLETIC ASSOCIATION
Minneapolis, Minn.

ARCHITECTS—Betram & Chamberland, Minneapolis, Minn.
CONSULTING ENGINEER—C. A. Pillsbury, Minneapolis, Minn.
HEATING AND PLUMBING CONTRACTORS—Belden, Porter and Gray
Minneapolis, Minn.

HOTEL FONTENELLE
Omaha, Neb.

ARCHITECT—Thomas Kimball, Omaha, Neb.
ENGINEERS—Nailor & Rich, Chicago, Ill.
HEATING CONTRACTORS—Newberry Electric Company
St. Louis, Mo.

HOTEL JEFFERSON
St. Louis, Mo.

ARCHITECTS—Barnett, Haynes & Barnett
CONTRACTORS—Westlake Construction Company

MARYLAND HOTEL
St. Louis, Mo.

ARCHITECT—A. B. Groves
CONTRACTORS—W. M. Sutherlin Construction Company

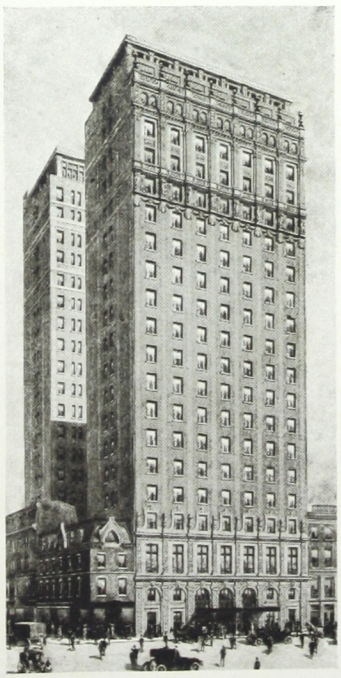
HOTEL UTAH
Salt Lake City, Utah

ARCHITECTS—Parkinson & Bergstrom, Los Angeles, Cal.
CONTRACTORS—James Stewart & Company
Salt Lake City, Utah and St. Louis, Mo.

HOTEL WASHINGTON
Seattle, Wash.

HOTEL ST. FRANCIS
San Francisco, Cal.

WINECOFF HOTEL
Atlanta, Ga.



HOTEL ADELPHIA
Philadelphia, Pa.

ARCHITECT—Horace Trumbauer
Philadelphia, Pa.
CONTRACTORS—Doak & Company
HEATING CONTRACTORS—Flynn & Company
PLUMBING CONTRACTORS—Baker-Smith & Co.

BENSEN HOTEL
Portland, Ore.

ARCHITECTS—Doyle, Patterson & Beach
CONTRACTORS—Sound Construction Company

BUCKINGHAM HOTEL
St. Louis, Mo.

ARCHITECT—H. F. Roach
CONTRACTORS—Southern Illinois Construction Company

WASHINGTON HOTEL
St. Louis, Mo.

ARCHITECTS—Eames & Young, St. Louis, Mo.
CONTRACTOR—James Black

HOTEL GALVEZ
Galveston, Texas

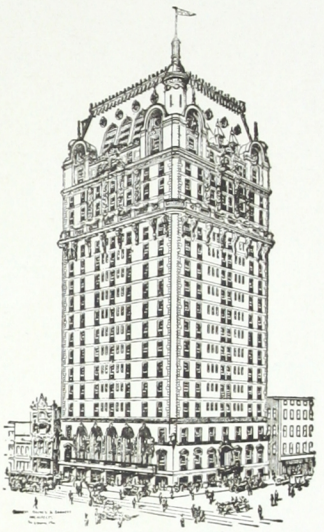
ARCHITECTS—Mauran & Russell, St. Louis, Mo. CONTRACTORS—James Stewart & Company, New York City

WALDORF APARTMENTS
Seattle, Wash.

DAVENPORT HOTEL & RESTAURANT
Spokane, Wash.

HOTEL CLARK
Los Angeles, Cal.

ARCHITECTS—Harrison-Albright Company, Los Angeles, Cal.
CONTRACTORS—F. O. Engstrum Company
HEATING AND PLUMBING CONTRACTORS—F. O. Engstrum Company



HOTEL ADOLPHUS
Dallas, Texas

ARCHITECTS—T. P. Barnett Architectural Company, St. Louis, Mo.
CONTRACTORS—Gilsonite Construction Company

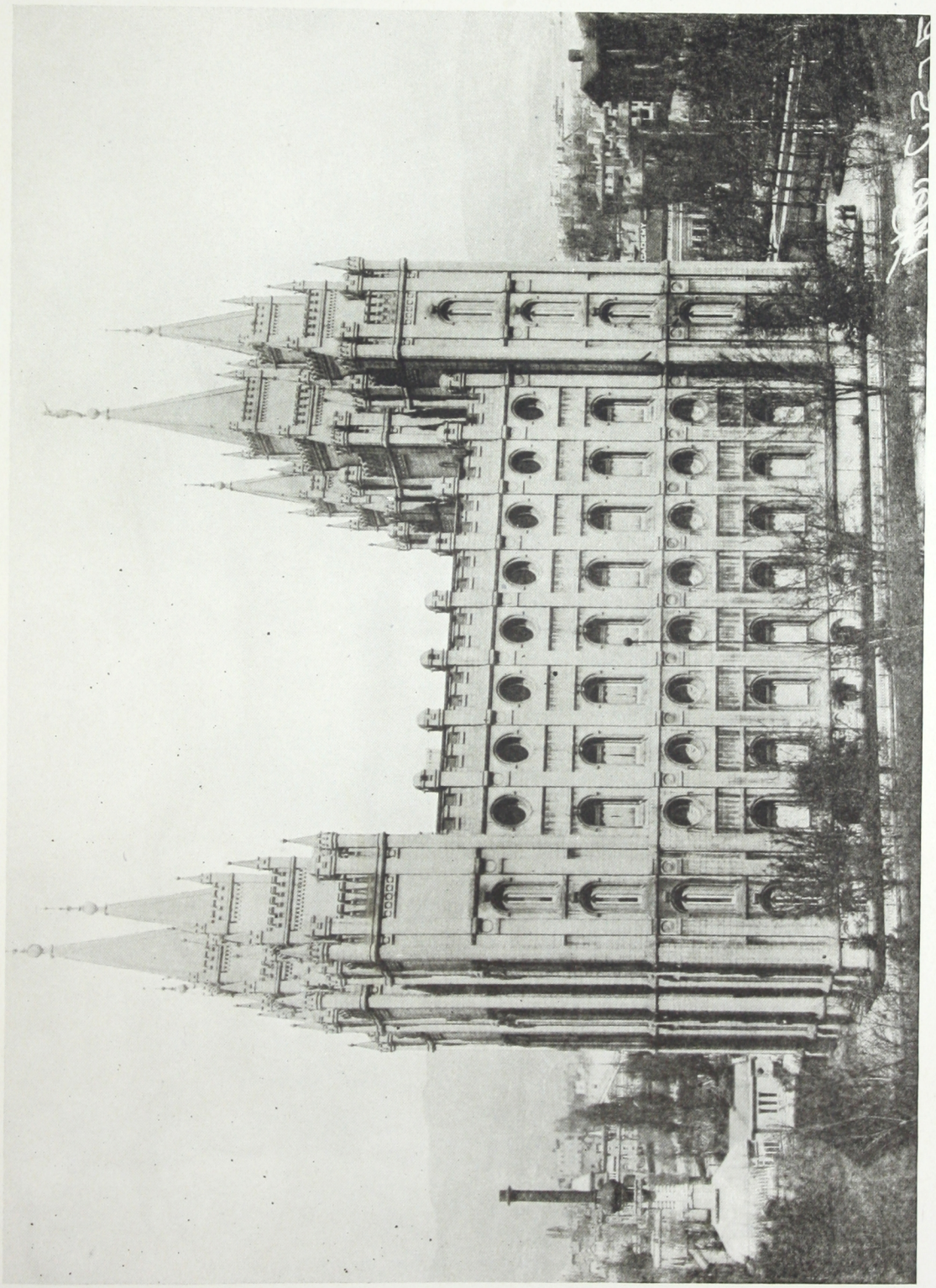
FAIRMONT HOTEL
San Francisco, Cal.

MULTNOMAH HOTEL
Portland, Ore.
CONTRACTORS—Brayton Engineering Company

PALACE HOTEL
San Francisco, Cal.

ELKS' CLUB
Brooklyn, N. Y.
ARCHITECT—H. Van Buren Magonigle
HEATING CONTRACTORS—Osborne, Rea & Co.
New York City

CHURCHES, UNIVERSITIES, SCHOOLS, LIBRARIES, THEATERS AND OTHER PUBLIC BUILDINGS

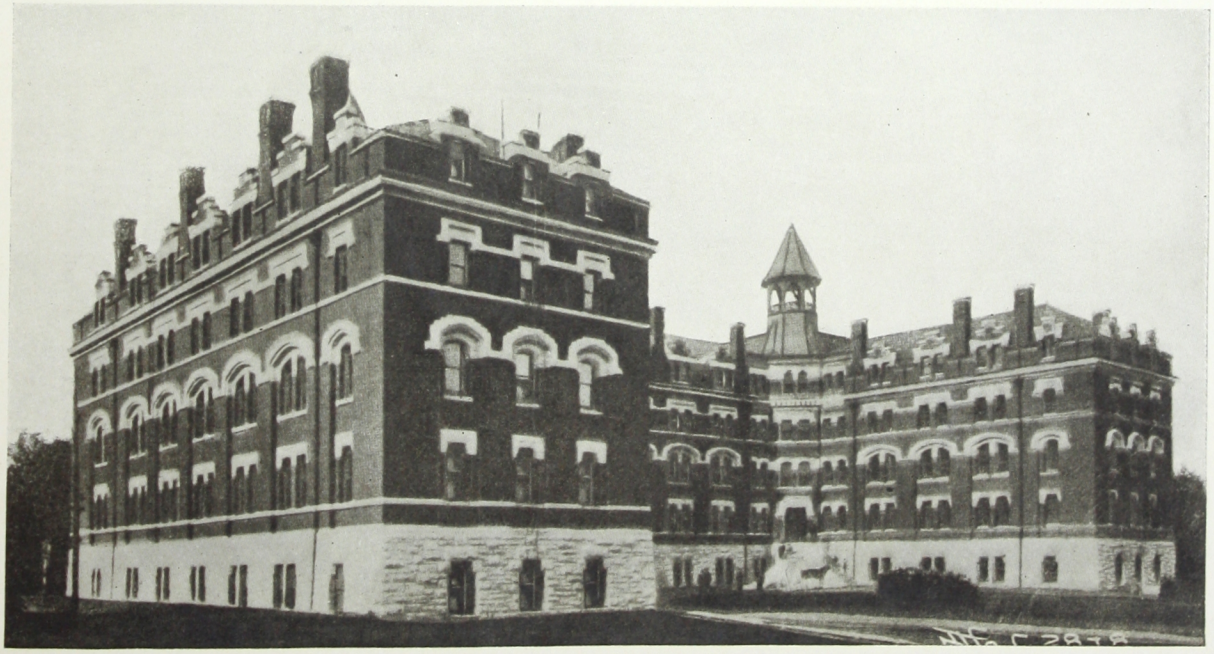


MORMON TEMPLE
Salt Lake City, Utah

FULTON COUNTY COURT HOUSE
Atlanta, Ga.
CONTRACTOR—Moise De Leon

NORTHWESTERN RAILWAY STATION
Chicago, Ill.

MICHIGAN CENTRAL RAILWAY STATION
Detroit, Mich.
ARCHITECT—E. W. Smith, Detroit, Mich.



KISSAM HALL
Vanderbilt University
Nashville, Tenn.

MISSOURI STATE CAPITAL
Jefferson City, Mo.

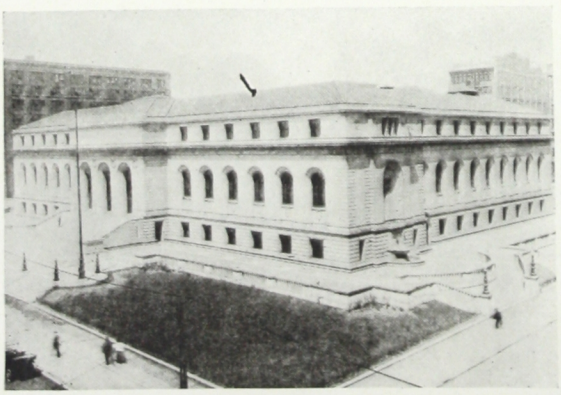
NEW THEATER BUILDING
Washington, D. C.

ARCHITECT—A. P. Clark, Washington, D. C.
HEATING CONTRACTORS—W. G. Cornell & Company
Washington, D. C.

Y. M. C. A. BUILDING
Nashville, Tenn.

PUBLIC LIBRARY
Portland, Ore.

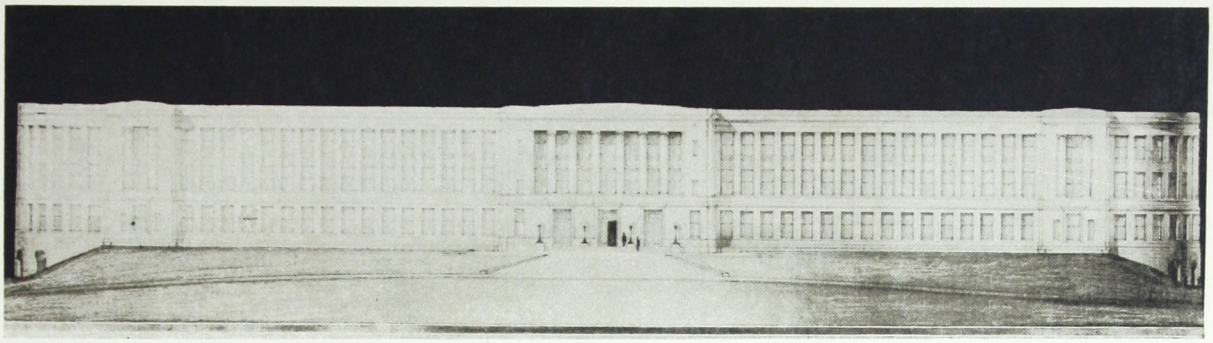
ARCHITECTS—Doyle & Patterson
CONTRACTORS—Pearson Construction Company



ST. LOUIS PUBLIC LIBRARY
(Main Building)
St. Louis, Mo.

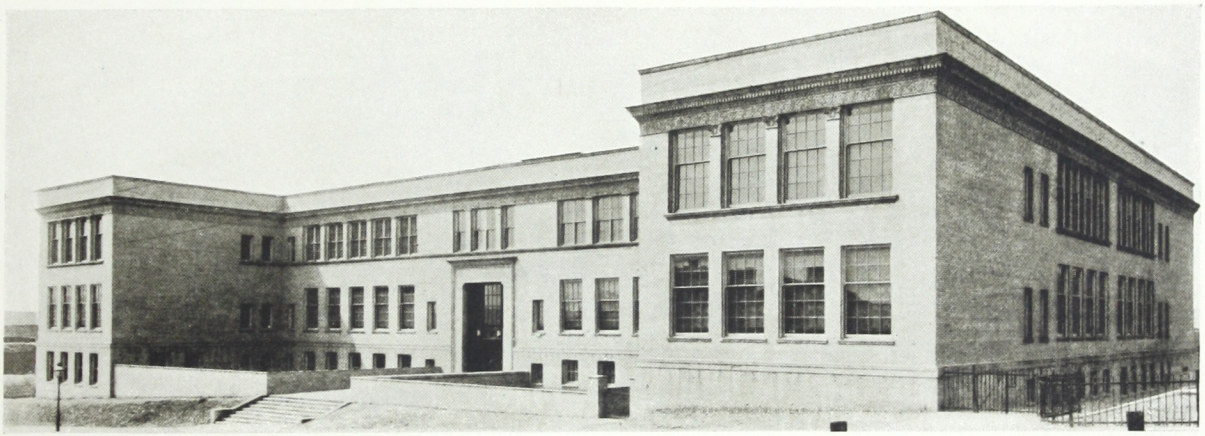
ARCHITECT—Cass Gilbert, New York City
CONTRACTORS—Pierce Construction Company

PROVIDENCE HOSPITAL
Seattle, Wash.



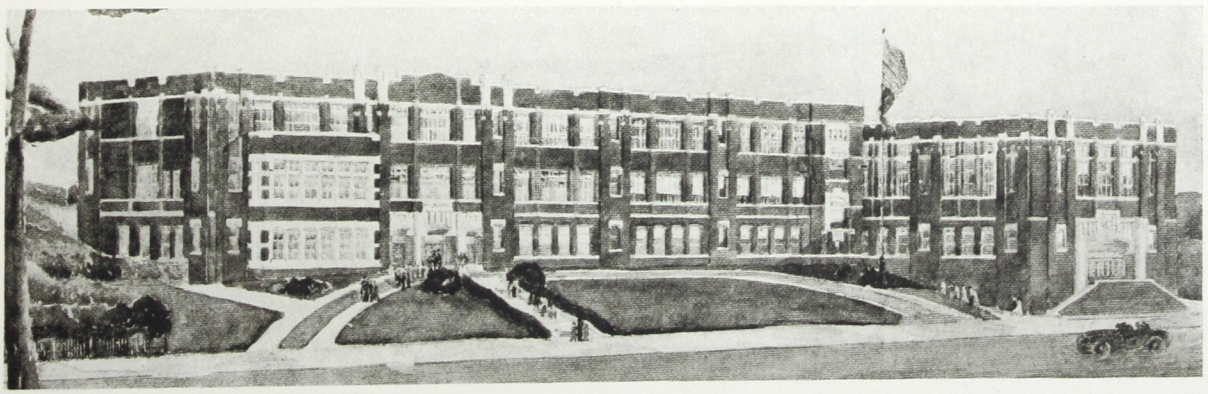
SCHENLEY HIGH SCHOOL
Pittsburgh, Pa.

ARCHITECT—Henry Stotz, Pittsburgh, Pa. CONTRACTORS—Thompson-Starrett Company
PLUMBING CONTRACTOR—W. N. Sauer, Pittsburgh, Pa. HEATING CONTRACTOR—HANLEY-CASEY MECHANICAL EQUIPMENT COMPANY, Chicago, Ill.



WATT GRADE SCHOOL
Pittsburgh, Pa.

ARCHITECTS—Ingham & Boyd, Pittsburgh, Pa. HEATING CONTRACTORS—Geo. F. Higgins & Company, Pittsburgh, Pa.
PLUMBING CONTRACTORS—Weldon & Kelly, Pittsburgh, Pa.

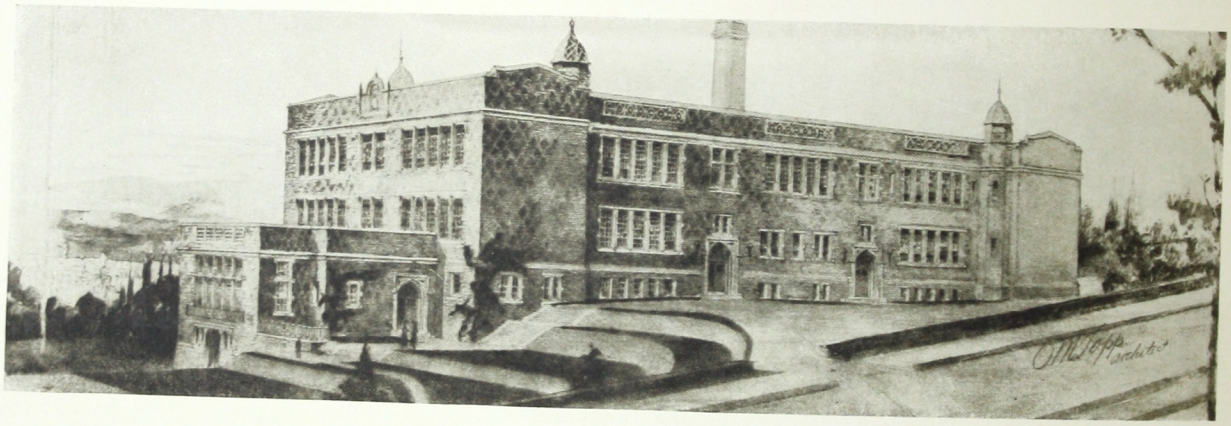


WM. H. McKELVIE GRADE SCHOOL
Pittsburgh, Pa.

ARCHITECT—Carlton Strong, Pittsburgh, Pa. HEATING CONTRACTOR—F. E. Giesler, Pittsburgh, Pa.
PLUMBING CONTRACTORS—Stinson-Kennedy Company, Pittsburgh, Pa.

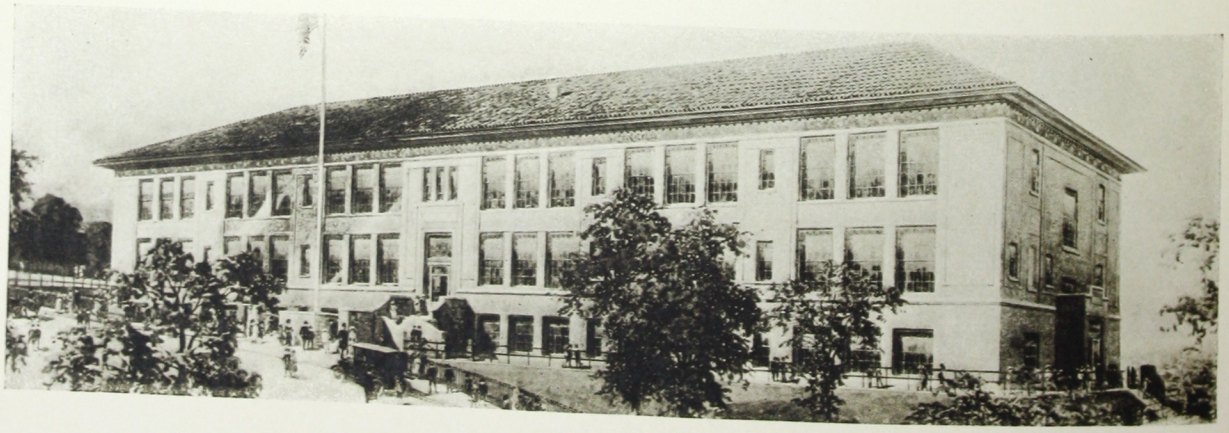
DILWORTH GRADE SCHOOL
Pittsburgh, Pa.

ARCHITECTS—Vrydaugh & Wolf, Pittsburgh, Pa. HEATING CONTRACTORS—Geo. F. Higgins & Company, Pittsburgh, Pa.
PLUMBING CONTRACTORS—Buerkle Plumbing Company, Pittsburgh, Pa.



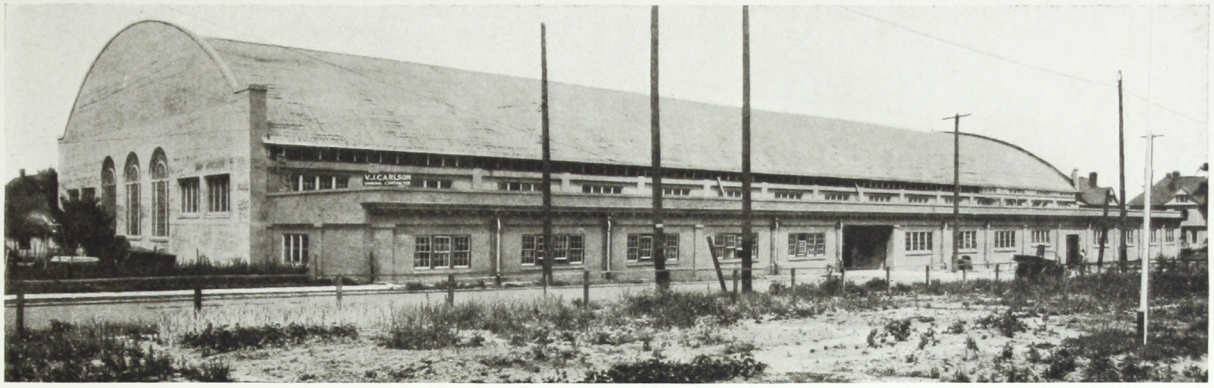
GLADSTONE GRADE SCHOOL
Pittsburgh, Pa.

ARCHITECT—O. M. Topp, Pittsburgh, Pa.

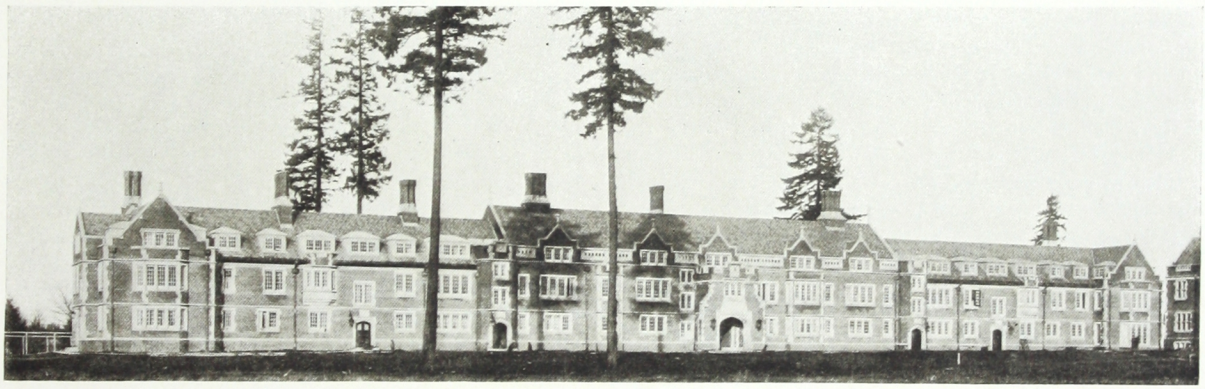


JAMES E. RODGERS GRADE SCHOOL
Pittsburgh, Pa.

ARCHITECTS—Janssen & Abbott, Pittsburgh, Pa.

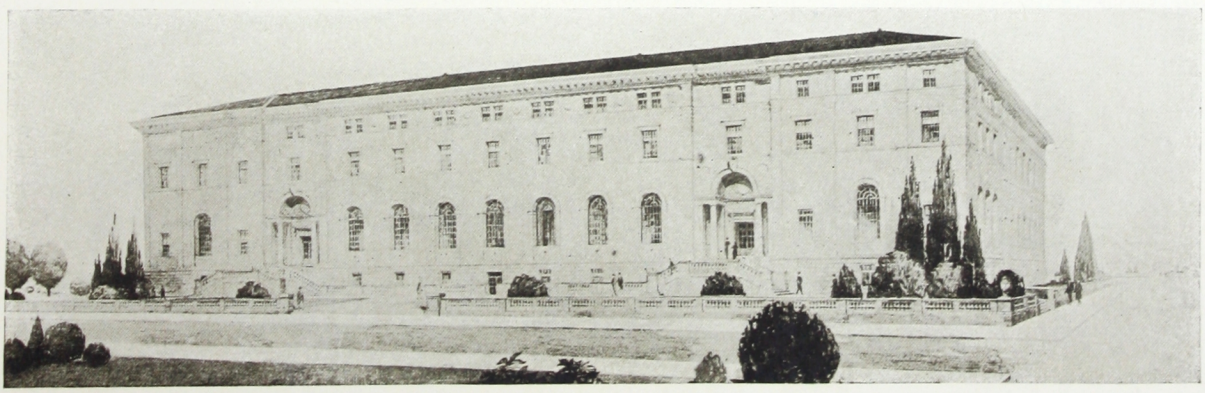


ICE HIPPODROME
Portland, Ore.



REED COLLEGE
Portland, Ore.

ARCHITECTS—Doyle & Patterson. CONTRACTORS—Sound Construction Company



ST. PAUL LIBRARY
St. Paul, Minn.

ARCHITECT—Electus Litchfield, New York City. CONSULTING ENGINEER—C. A. Pillsbury, Minneapolis, Minn.
HEATING AND PLUMBING CONTRACTORS—Healy Plumbing and Heating Company, St. Paul, Minn.

THE DESIGN OF HOT-WATER SUPPLY SYSTEMS TO MINIMIZE CORROSION

By F. N. SPELLER[14]

Reprinted from Engineering News, Issue of February 13, 1913, Page 294

SUGGESTED DESIGN

IN a paper on the "Durability of Welded Steel Pipe",[15] reprinted and commented upon in Engineering News, March 23, 1911, there were discussed the results of investigations on the relative corrosion of iron and steel in service, and the influence of the dissolved gases (oxygen and carbonic acid) in water and a scheme was suggested for rendering the water practically harmless by removing the air after heating. So far as the writer is aware, however, no system has yet been designed with this as the main object.

COMPARISONS ON PITTING

In the paper referred to the writer pointed out first, that the superiority claimed for "genuine" wrought iron pipe had not been proved by comparative tests in service; on the contrary, the numerous cases which are on record (and which have been largely added to since that time), show conclusively that where both iron and steel have been used together in water lines, the wrought iron pits just as badly as the steel under the same conditions. A number of such comparisons were compiled by the writer for the International Congress for Testing Materials last September.[16]

AUTHORITIES AGREE

We need not again go into the cause of this pitting, which is now generally recognized to be due to galvanic action between impurities on the surface of the metal, especially mill scale and rust. The leading authorities now seem agreed that corrosion is practically independent of the composition of the metal, provided it is reasonably uniform (as the steel used for welded pipe must necessarily be if it welds without developing injurious defects).

In order to have continued corrosion, oxygen must be present in solution; the removal of this oxygen has been found to greatly lessen corrosion. In his recent report of researches along this line, Dr. W. H. Walker, director of the research laboratory of the Massachusetts Institute of Technology, describes one of his experiments thus:[17]

> "Two coils made up from pieces taken from the same length of pipe were each fed with water from the same source at the same temperature. In one case the water was heated to 85 degrees Cent. in an open tank, while in the other the water was heated to the same temperature in a closed tank. The feed water contained on the average 5.85 c. c. of oxygen per liter, and passed through each coil at the rate of one-half gallon per minute. After running 1750 hours, the coil fed with water heated in an open tank had lost 22 grams, while the coil fed with water heated in a closed tank had lost 155 grams. In neither case was the oxygen completely removed; if the water in the open tank had been gently boiled, corrosion in the coil fed with this water would have been completely prevented."

These results again indicate that the intensity of conditions has much more to do with corrosion than anything else; so much so that the same material used as a pipe in a hot-water heating system, where the water is practically free from oxygen and unchanged, should last 50 years or more, while in a closed hot-water supply system it may only last five or six years.

This principle of heating and freeing the water from dissolved oxygen, by which it seems possible to prolong the life of standard welded pipe several times, is surely worthy of careful consideration in designing piping systems which are subject to corrosion.

A recent investigation, undertaken by the writer with the assistance of some of his research staff, has developed interesting points in regard to the present practice of laying out hot-water supply systems. The influence of the arrangement of the piping on corrosion seems to be quite marked, depending on whether the gases are liberated before the water enters the distributing system or not, although the separation of these gases is only partially accomplished under the best conditions. Large installations were considered, such as hotels, large apartments and office buildings where, on account of the great quantity of hot water used, serious trouble would be most likely to occur.

CLASSES OF SYSTEMS

The hot-water supply systems found in these buildings differed in many details, but may be divided into two classes, according to whether the main vertical distributing lines are supplied from a common horizontal main in the basement, or from a similar horizontal distributing main above the level of the highest fixture near the roof. These types of installations are illustrated, diagrammatically and without detail of any kind, in Figs. 1 and 2.

UNDERFED SYSTEM

The underfed system is characterized by a number of independent risers and return-risers, each supplying a separate section of the building. These risers are rarely vented at the top and consequently the hot water is always super-saturated with air when the system is in continuous use. This is a good example of the closed type of heating so designed that it would be very difficult, if not entirely impracticable, to vent so as to remove the gases before the water is used.

[14] Metallurgical Engineer, National Tube Company, Frick Bldg., Pittsburgh, Pa.

[15] Proceedings, American Society of Heating and Ventilating Engineers, 1911.

[16] "Comparative Service Obtained with Wrought Iron and Soft Steel Pipes as Water Lines in the United States", Proc., International Association for Testing Materials, 1912. XXIV, 4.

[17] "Engineering News", Dec. 21, 1911; "Journal of New England Water Works Association", March, 1912; "Journal of Industrial and Engineering Chemistry", July, 1912.

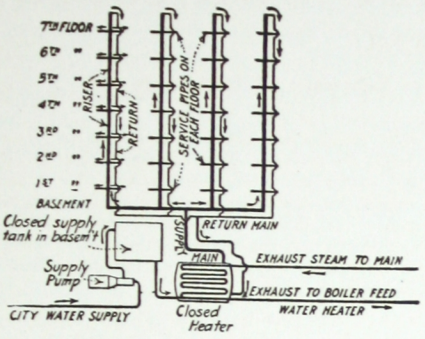


Fig. 1. Underfed Closed System

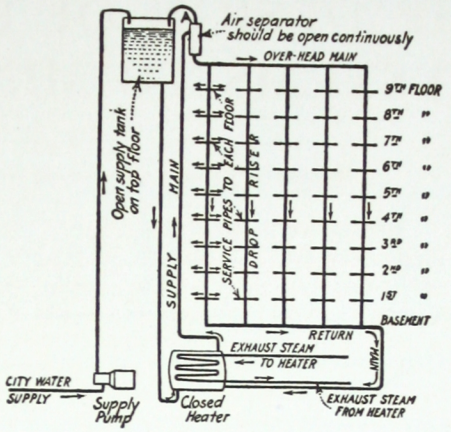


Fig. 2. Overhead Open System

Figs. 1 and 2. Two Types of Hot-water Supply Systems

OVERHEAD OPEN SYSTEM

The system illustrated by Fig. 2, on the other hand, is radically different in this respect, and to a considerable extent, although not completely, allows the escape of dissolved gases to the atmosphere at the highest point before the water is distributed throughout the system and returns to the heater. Since all the water used passes up through one riser a vent must be provided, otherwise trouble due to the trapping of air in the upper lines would probably be experienced. It would seem to be a very simple matter to almost completely free the water from dissolved gases with such a system, by putting a simple air-separating device at the upper end of the main riser, as indicated at the point A in Fig. 2. To obtain the best results, the water should be heated to about 200 degrees Fahr., using an inter-cooler, if desired, to reduce the temperature after leaving the air-separating chamber.

The writer has discussed only general principles affecting the life of the piping system; the details necessary to carry out these principles in practice, will, of course, require thought and expert knowledge of design on the part of practical engineers having to do with heating and plumbing.

With pure water, such as is supplied to New York City for example, the percentage of dissolved gases is proportionately high, so that the benefit to be expected from such treatment when thoroughly carried out and maintained would probably be very marked.

Several cases investigated, where large systems of hot-water supply lines have suffered serious damage in six or eight years, have all occurred in buildings equipped with closed heating systems. So far, we have not found serious trouble in systems of the open type where any attention has been given to venting, although the significance of adequate venting of such systems does not seem to be appreciated by architects and engineers, for in some cases, where vents were provided, the practice was to keep them closed except when trouble with air-hammer was experienced.

Engineers and architects have perhaps hesitated to make changes in the closed system of heating without more practical evidence of a substantial character, the scientific study of corrosion being all new ground. The writer hopes to see a free discussion, on the part of those who have most experience in such work, so that the best system of design may be developed for such installations with due regard to prevention of corrosion.

MARKING

Name Rolled in Raised Letters on National Tube Company Pipe

SPECIFICATION FOR "NATIONAL" STANDARD WELDED PIPE

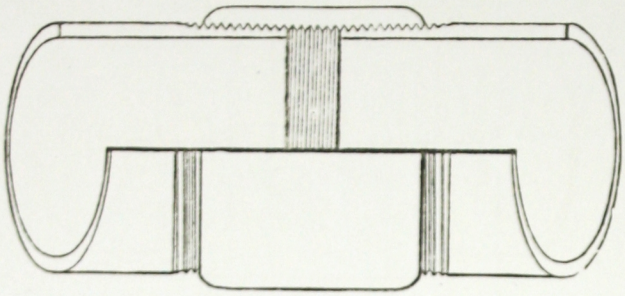


Fig. 3. Typical Section of "NATIONAL" Standard Pipe Coupling and Joint

(1) MATERIAL—Welded pipe is to be made of uniformly good quality soft weldable steel rolled from solid ingots. Sufficient crop shall be cut from the ends to insure sound material, and the steel shall be given the most approved treatment in heating and rolling.

(2) PROCESS OF MANUFACTURE—All pipe shall be made either by the lap or butt weld process as specified on order according to the best methods and practice.

(3) SURFACE INSPECTION—The pipe must be reasonably straight and free from blisters, cracks or other injurious defects. Liquor marks incidental to the manufacture of lap weld pipe will not be considered as surface defects. The pipe shall not vary more than one per cent either way from being perfectly round or true to the standard outside diameter, except on the small sizes where a variation of $\frac{1}{64}$ of an inch will be accepted. The pipe must not vary more than five per cent either way from standard weight.

(4) THREADING AND REAMING—Where required, the pipe must have a good Briggs' Standard thread, which will make a tight joint when tested by hydraulic pressure at the mill (paragraph 5). The thread must not vary more than one and one-half turns either way when tested with a Pratt & Whitney Briggs' Standard gauge. All burrs at the ends are to be removed.

(5) INTERNAL PRESSURE TEST—The following test pressures will be applied to the respective sizes of standard butt and lap weld pipe as indicated in table:

Nominal Size	Method of Manufacture	Test Pressure
⅜ inch to 2 inches (inc.)	Butt Weld	700 pounds
2½ inches and 3 inches	Butt Weld	800 pounds
Up to 8 inches	Lap Weld	1000 pounds
9 and 10 inches	Lap Weld	900 pounds
11 and 12 inches	Lap Weld	800 pounds
13 and 14 inches	Lap Weld	700 pounds
15 inches	Lap Weld	600 pounds

NOTE—On eight, ten and twelve inch sizes which have more than one weight as standard, we have shown the hydraulic test pressure for the heaviest weight.

(6) TESTING OF MATERIAL—The steel from which the pipe is made must show the following physical properties:

Tensile Strength	Over 50,000 pounds
Elastic Limit	Over 30,000 pounds
Elongation in 8 inches	18 per cent
Reduction in area	50 per cent

A test piece cut lengthwise from the pipe and filed smooth on the edges should bend through 180 degrees with an inner diameter at the bend equal to the thickness of the material, without fracture.

(7) COUPLINGS—The material to be sound and free from injurious defects. Threads must be clean cut, tapped straight through and of such pitch diameter as will make a tight joint. The ends must be countersunk.

(8) THREAD PROTECTION—Solid tapped rings or split couplings will be provided as thread protectors on all sizes four inches in diameter or larger. Protection will be provided for smaller sizes when specifically called for on order.

(9) TESTS—All tests shall be made at mill.

"NATIONAL" PIPE

Full Standard Weight—Black and Galvanized

All Weights and Dimensions are Nominal

Size	List Price per Foot	Diameters		Thickness	Weight per Foot		Threads per Inch
		External	Internal		Plain Ends	Threads and Couplings	
⅛	$ .05⅛	.405	.269	.068	.244	.245	27
¼	.06	.540	.364	.088	.424	.425	18
⅜	.06	.675	.493	.091	.567	.568	18
½	.08⅛	.840	.622	.109	.850	.852	14
¾	.11⅛	1.050	.824	.113	1.130	1.134	14
1	.17	1.315	1.049	.133	1.678	1.684	11½
1¼	.23	1.660	1.380	.140	2.272	2.281	11½
1½	.27⅛	1.900	1.610	.145	2.717	2.731	11½
2	.37	2.375	2.067	.154	3.652	3.678	11½
2½	.58⅛	2.875	2.469	.203	5.793	5.819	8
3	.76⅛	3.500	3.068	.216	7.575	7.616	8
3½	.92	4.000	3.548	.226	9.109	9.202	8
4	1.09	4.500	4.026	.237	10.790	10.889	8
4½	1.27	5.000	4.506	.247	12.538	12.642	8
5	1.48	5.563	5.047	.258	14.617	14.810	8
6	1.92	6.625	6.065	.280	18.974	19.185	8
7	2.38	7.625	7.023	.301	23.544	23.769	8
8	2.50	8.625	8.071	.277	24.696	25.000	8
8	2.88	8.625	7.981	.322	28.554	28.809	8
9	3.45	9.625	8.941	.342	33.907	34.188	8
10	3.20	10.750	10.192	.279	31.201	32.000	8
10	3.50	10.750	10.136	.307	34.240	35.000	8
10	4.12	10.750	10.020	.365	40.483	41.132	8
11	4.63	11.750	11.000	.375	45.557	46.247	8
12	4.50	12.750	12.090	.330	43.773	45.000	8
12	5.07	12.750	12.000	.375	49.562	50.706	8
13	5.60	14.000	13.250	.375	54.568	55.824	8
14	6.10	15.000	14.250	.375	58.573	60.375	8
15	6.50	16.000	15.250	.375	62.579	64.500	8

The permissible variation in weight is 5 per cent above and 5 per cent below.

Furnished with threads and couplings and in random lengths unless otherwise ordered.

All weights given in pounds. All dimensions given in inches.

For cut lengths, an extra charge will be made above random lengths.

For pipe smoothed on the inside, known as reamed and drifted, an extra charge will be made above standard pipe.

For Galvanized, or Coated pipe, an extra charge will be made above Black.

"NATIONAL" PIPE

Extra Strong Pipe—Double Extra Strong Pipe

Full Standard Weight

Extra Strong Pipe—Black and Galvanized

All Weights and Dimensions are Nominal

Size	List Price per Foot	Diameters		Thickness	Weight per Foot Plain Ends
		External	Internal		
⅛	$ .12	.405	.215	.095	.314
¼	.07½	.540	.302	.119	.535
⅜	.07½	.675	.423	.126	.738
½	.11	.840	.546	.147	1.087
¾	.15	1.050	.742	.154	1.473
1	.22	1.315	.957	.179	2.171
1¼	.30	1.660	1.278	.191	2.996
1½	.36½	1.900	1.500	.200	3.631
2	.50½	2.375	1.939	.218	5.022
2½	.77	2.875	2.323	.276	7.661
3	1.03	3.500	2.900	.300	10.252
3½	1.25	4.000	3.364	.318	12.505
4	1.50	4.500	3.826	.337	14.983
4½	1.80	5.000	4.290	.355	17.611
5	2.08	5.563	4.813	.375	20.778
6	2.86	6.625	5.761	.432	28.573
7	3.81	7.625	6.625	.500	38.048
8	4.34	8.625	7.625	.500	43.388
9	4.90	9.625	8.625	.500	48.728
10	5.48	10.750	9.750	.500	54.735
11	6.10	11.750	10.750	.500	60.075
12	6.55	12.750	11.750	.500	65.415

The permissible variation in weight is 5 per cent above and 5 per cent below.

Double Extra Strong Pipe—Black and Galvanized

All Weights and Dimensions are Nominal

Size	List Price per Foot	Diameters		Thickness	Weight per Foot Plain Ends
		External	Internal		
½	$ .32	.840	.252	.294	1.714
¾	.35	1.050	.434	.308	2.440
1	.37	1.315	.599	.358	3.659
1¼	.52½	1.660	.896	.382	5.214
1½	.65	1.900	1.100	.400	6.408
2	.91	2.375	1.503	.436	9.029
2½	1.37	2.875	1.771	.552	13.695
3	1.86	3.500	2.300	.600	18.583
3½	2.30	4.000	2.728	.636	22.850
4	2.76	4.500	3.152	.674	27.541
4½	3.26	5.000	3.580	.710	32.530
5	3.86	5.563	4.063	.750	38.552
6	5.32	6.625	4.897	.864	53.160
7	6.35	7.625	5.875	.875	63.079
8	7.25	8.625	6.875	.875	72.424

The permissible variation in weight is 10 per cent above and 10 per cent below.
The following notes apply to both tables:
Furnished with plain ends and in random lengths, unless otherwise ordered.
All weights given in pounds. All dimensions given in inches.
Random length of Extra Strong and Double Extra Strong pipe is considered to be 12 feet to 22 feet, we to have the privilege, however, of supplying not exceeding 5 per cent of total order in lengths from 6 feet to 12 feet.
For pipe fitted with threads and couplings, an extra charge will be made above plain ends.
For cut lengths, an extra charge will be made above random.
For Galvanized, or Coated pipe, an extra charge will be made above Black.

"NATIONAL" AIR LINE PIPE

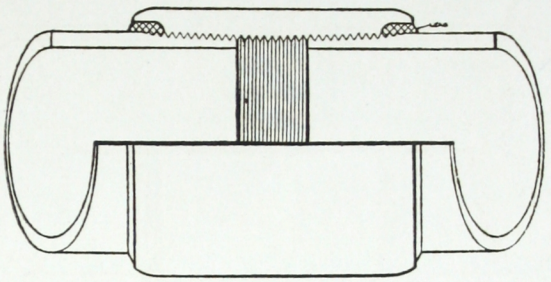


Fig. 4. Typical Section of "NATIONAL" Air Line Pipe Coupling and Joint

"NATIONAL" AIR LINE PIPE

All Weights and Dimensions are Nominal

Size	List Price per Foot	Diameters		Thickness	Weight Per Foot		Threads per Inch	Couplings		
		External	Internal		Plain Ends	Thr'ds and Couplings		Diameter	L'gth	Wt.
1½	$ .30	1.900	1.582	.159	2.956	3.00	11½	2.387	2 15/16	1.364
2	.40	2.375	2.043	.166	3.916	4.00	11½	2.976	3½	2.416
2½	.65	2.875	2.423	.226	6.393	6.50	8	3.544	4	3.772
3	.90	3.500	2.990	.255	8.837	9.00	8	4.272	4½	5.899
4	1.18	4.500	3.996	.252	11.433	11.75	8	5.500	4½	9.124
5	1.70	5.563	4.977	.293	16.491	17.00	8	6.652	6	16.720
6	2.10	6.625	6.025	.300	20.265	21.00	8	7.833	6	21.826

The permissible variation in weight is 5 per cent above and 5 per cent below.
Furnished with threads and couplings and in random lengths, unless otherwise ordered.
The above pipe is fitted with special air line couplings recessed for lead calking.
All weights given in pounds. All dimensions given in inches.

SPECIFICATION FOR "NATIONAL" SPECIAL AMMONIA PIPE

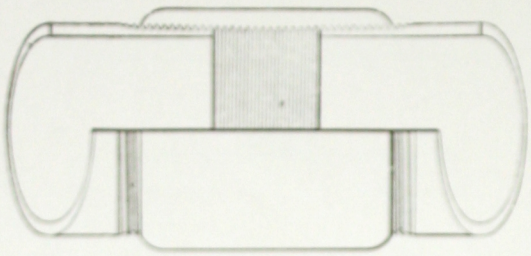


Fig. 5. Typical Section of "NATIONAL" Special Ammonia Pipe Coupling and Joint

(1) **MATERIAL**—Welded pipe is to be made of uniformly good quality soft weldable steel rolled from solid ingots. Sufficient crop shall be cut from the ends to insure sound material, and the steel shall be given the most approved treatment in heating and rolling.

(2) **PROCESS OF MANUFACTURE**—All pipe two inches and larger to be lap welded; smaller sizes to be butt welded and redrawn from a larger size.

(3) **SURFACE INSPECTION**—Pipe must be reasonably straight and free from blisters, cracks or other injurious defects. Liquor marks incidental to the manufacture of lap welded pipe will not be considered as surface defects. The pipe shall not vary more than one per cent either way from being perfectly round or true to standard outside diameter, except on the small sizes where a variation of $\frac{1}{64}$ of an inch will be permitted. The pipe must not vary more than five per cent either way from the weight specified.

(4) **THREADING AND REAMING**—Where required, pipe must have a good Briggs' Standard thread, which will make a tight joint when tested by hydraulic pressure at the mill (paragraph 5). The thread must not vary more than one and one-half turns either way when tested with a Pratt & Whitney Briggs' Standard gauge. All burrs at the ends are to be removed.

(5) **INTERNAL PRESSURE TEST**—Each length of "NATIONAL" Special Ammonia Pipe when lap welded shall be tested at the mill to 2000 pounds hydrostatic pressure; when butt welded and redrawn, the test pressure shall be 1500 pounds.

(6) **TESTING OF MATERIAL**—The steel from which the pipe is made must show the following physical properties:

Tensile Strength	Over 50,000 pounds
Elastic Limit	Over 30,000 pounds
Elongation in 8 inches	Not less than 20 per cent
Reduction in area	Not less than 50 per cent

A test piece cut lengthwise from the pipe and filed smooth on the edges shall bend through 180 degrees with an inner diameter at the bend equal to the thickness of the material, without fracture.

(7) **COUPLINGS**—The material to be sound and free from injurious defects. Threads must be clean cut, tapered same as pipe, and of such pitch diameter as will make a tight joint. The ends must be countersunk.

(8) **THREAD PROTECTION**—Solid tapped rings or split couplings will be provided as thread protectors on pipe two inches and larger. Thread protection will be provided for smaller sizes when specifically called for on order.

(9) **TESTS**—All tests shall be made at mill.

"NATIONAL" SPECIAL AMMONIA PIPE—REDRAWN OR LAP WELDED

All Weights and Dimensions are Nominal

Size	Diameters		Thickness	Weight per Foot		Threads per Inch	Test Pressure in Pounds	Couplings		
	External	Internal		Plain Ends	Threads and Couplings			Diameter	Length	Weight
1¼	1.660	1.380	.140	2.272	2.297	11½	1500	2.031	2½	.992
1½	1.900	1.610	.145	2.717	2.744	11½	1500	2.271	2½	1.125
2	2.375	2.067	.154	3.652	3.706	11½	2000	2.817	3½	2.098

The permissible variation in weight is 5 per cent above and 5 per cent below.

Furnished with threads and couplings and in random lengths unless otherwise ordered.

Taper of threads is $\frac{3}{4}$ inch diameter per foot length for all sizes.

The weight per foot of pipe with threads and couplings is based on a length of 20 feet, including the coupling, but shipping lengths of small sizes will usually average less than 20 feet.

1¼ inch and 1½ inch sizes are butt welded and redrawn from a larger size; 2 inch size is lap welded.

All weights given in pounds. All dimensions given in inches.

For illustration showing joint see above.

WROUGHT PIPE BENDS[18]

The attached table gives the advisable radius and the least radius to which pipe of standard thickness may be bent when heated.

The radii given are as short as should be used to secure good results and if they be reduced, the thickness of the pipe must be increased. As the radius is decreased, however, it becomes more difficult to avoid buckles.

For making bends, we suggest pipe as follows:

Bends 12 inch and smaller to regular dimensions to be made of full-weight pipe.

Bends 14, 15 and 16 inch outside diameter to be not less than $\frac{3}{8}$ inch thick.

Bends 18 inch outside diameter and larger to be not less than $\frac{7}{16}$ inch to $\frac{1}{2}$ inch thick.

For offset bends try to make a straight length between the bends in preference to the direct reverse bend. This is of advantage to the pipe bender.

With the welded flanges there must be a short straight length of pipe between the bend and the flange. On sizes under 4 inches this should equal, at least, one and a half diameters. On sizes over 4 inches it should equal, at least, one diameter of the pipe. In all cases it is better if equal to two diameters of straight pipe.

Bent Tubes

These are more difficult to bend than standard weight pipe. Try not to vary from the advisable radius given in the table. With tubes it is frequently necessary to increase the thickness over that of standard boiler tubes in order to bend them.

Table of Radii for Wrought Pipe Bends

Pipe size Inches	Advisable radius—*R* Inches	Minimum radius—*R* Inches
$2\frac{1}{2}$	15	10
3	18	12
$3\frac{1}{2}$	21	14
4	24	16
$4\frac{1}{2}$	27	18
5	30	20
6	36	24
7	42	28
8	48	32
9	54	36
10	60	40
11	66	44
12	72	48
13	84	60
14	90	68
15	100	76
18 O. D.	125	90
20 O. D.	150	120
22 O. D.	165	132
24 O. D.	180	144

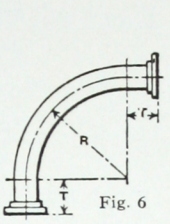
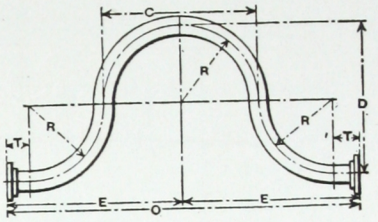
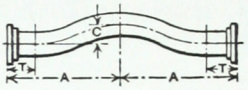


Fig. 6
90° Bend

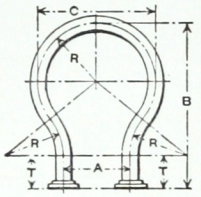


Expansion U Bend
Fig. 7

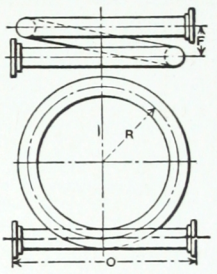


Cross Over
Fig. 8

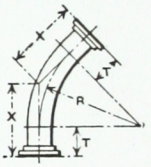
Offset
Fig. 11



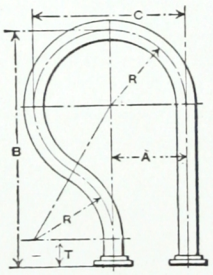
Double Offset U Bend
Fig. 9



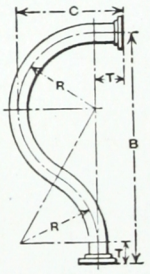
Expansion Loop
Fig. 10



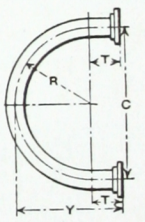
45° Bend
Fig. 12



Single Offset U Bend
Fig. 13



Single Offset 90° Bend
Fig. 14



U Bend
Fig. 15

HAND RAILINGS[19]

The use of pipe and fittings for hand railings around area ways, on stairs, for office enclosures with gates and for permanent ladders, is illustrated by the following set of cuts, which are typical of many installations which might be made. The construction of hand railings of such materials commends itself, first, on the ground of durability due to material used; second, neatness of design and detail; third, safety due to strength; and fourth, cheapness of construction. The illustrations show methods of assembling, which can be differentiated in a great many ways, and have been found successful and economical.

Regular railing fittings, such as shown by figures H-164 to H-172 inclusive, are furnished recessed, so that all short threads will be covered. Other railing fittings may be furnished in the same manner. Fittings of special angles can also be furnished when required, at special prices, but it is our experience that the regular patterns can be used in almost all cases, regardless of the angles involved, either by bending the pipe, as in Fig. 21, or by the use of extra fittings, as in Fig. 22.

The numbers on the illustrations with the letter "H" in front refer to National Tube Company's Catalogue H, issue 1909.

NOTE. All threads right-hand. Thread double length where indicated. Numbers given refer to catalogue numbers.

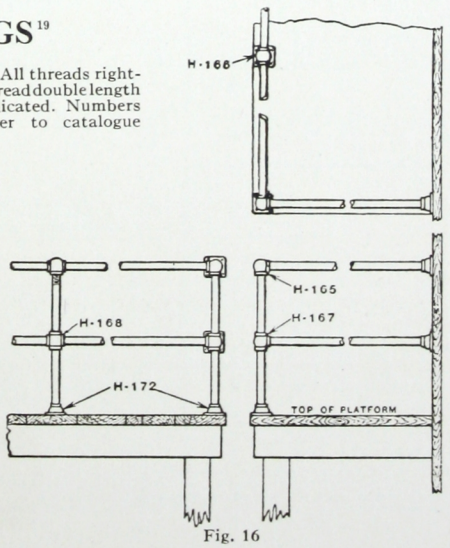


Fig. 16

[18] Book of Standards (National Tube Company) 1913 Edition, pages 162-163.

[19] Book of Standards (National Tube Company) 1913 Edition, pages 177-186.

HAND RAILINGS, ETC.

Some Uses of "NATIONAL" Pipe

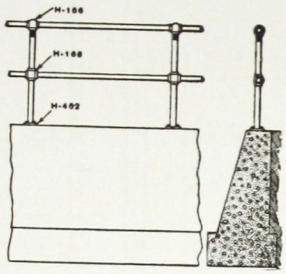


Fig. 17

NOTE. All threads right-hand. Thread double length where indicated. Numbers given refer to catalogue numbers.

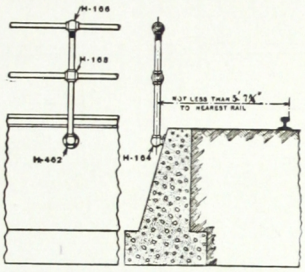


Fig. 18

NOTE. All threads right-hand. Thread double length where indicated. Numbers given refer to catalogue numbers.

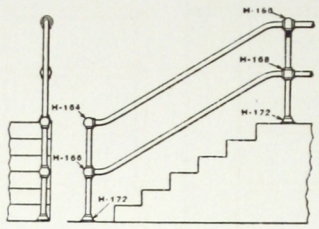


Fig. 21

NOTE. Standard fittings used and pipes bent to suit any angle of steps. All threads right-hand. Thread double length where indicated. Numbers given refer to catalogue numbers.

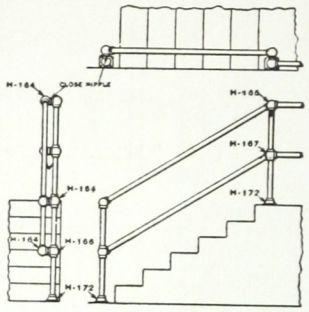


Fig. 22

NOTE. Standard fittings are suitable for any angle of steps. All threads right-hand. Thread double length where indicated. Numbers given refer to catalogue numbers.

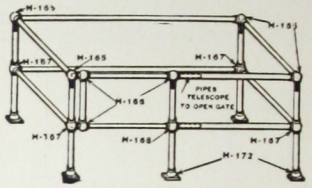


Fig. 25

NOTE. All threads right-hand. Thread double length where indicated. Numbers given refer to catalogue number.

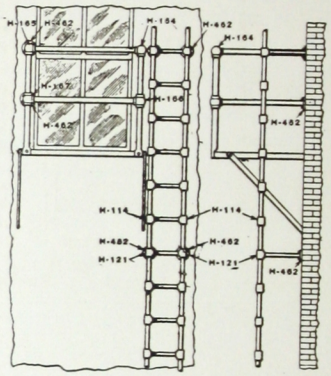


Fig. 26

NOTE. All threads right-hand. Thread double length where indicated. Numbers given refer to catalogue numbers.

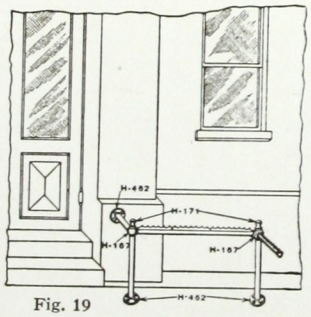
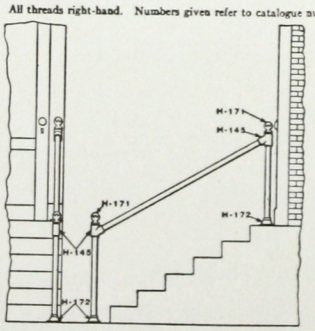


Fig. 19

NOTE. All threads right-hand. Numbers given refer to catalogue numbers.



NOTE. Suitable for steps at 30° angle. All threads right-hand. Numbers given refer to catalogue numbers.

Fig. 20

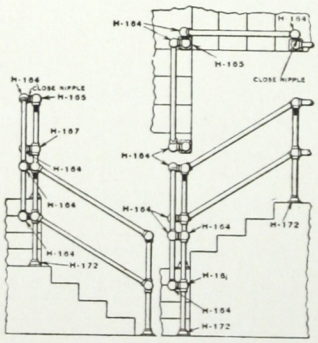


Fig. 23

NOTE. Standard fittings are suitable for any angle of steps. All threads right-hand. Thread double length where indicated. Numbers given refer to catalogue number.

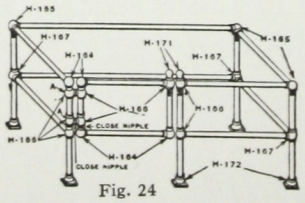


Fig. 24

NOTE. Fittings marked "A" are bored to turn on pipes for hinges. All threads right-hand. Thread double length where indicated. Numbers given refer to catalogue number.

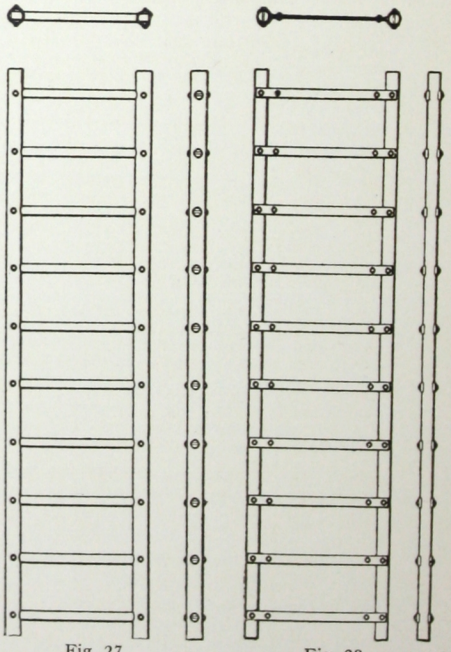


Fig. 27
Round Pipe Rungs
Round Pipe Runners

Fig. 28
Flat Bar Rungs
Round Pipe Runners

Typical Pipe Ladders

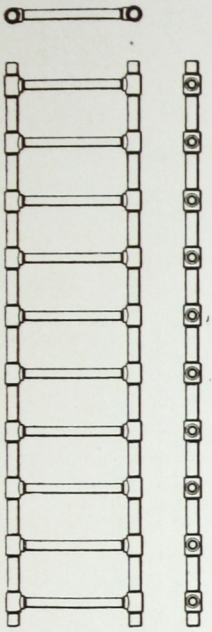


Fig. 29
Round Pipe Rungs
Round Pipe Runners
Typical Pipe Ladders

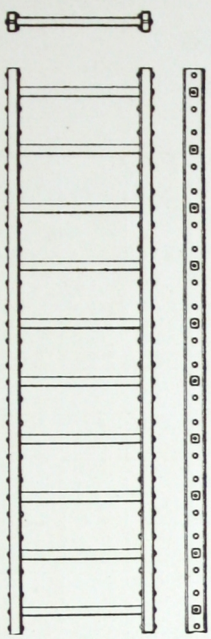


Fig. 30
Square Pipe Rungs
Rectangular Pipe Runners

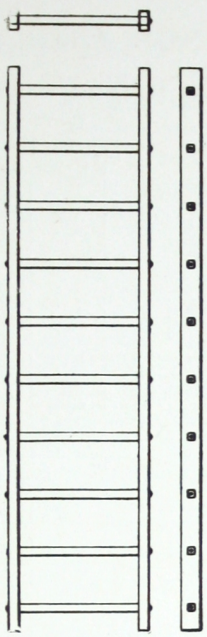


Fig. 31
Square Pipe Rungs
Rectangular Pipe Runners
Typical Pipe Ladders

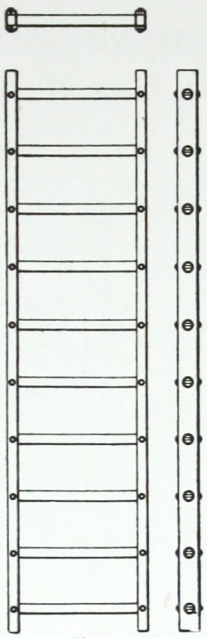


Fig. 32
Round Pipe Rungs
Rectangular Pipe Runners

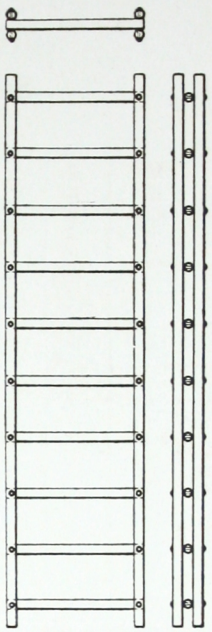


Fig. 33
Round Pipe Rungs
Round Pipe Runners
Typical Pipe Ladders

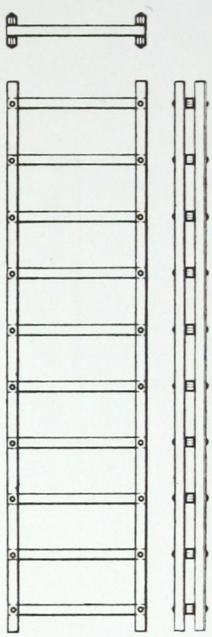


Fig. 34
Square Pipe Rungs
Square Pipe Runners

PROPERTIES OF PIPE[20]

$$\text{Strength factor } Q = \frac{\text{foot pounds}}{1000} = \frac{I}{y} \times \frac{27\,000}{1\,000} \times \frac{1}{12} = \frac{9}{2}\frac{I}{\text{O. D.}},$$

y = distance of farthest fiber from axis.

External diameter O. D.	Thickness	Weight per foot	Moment of inertia I	Section modulus I/y	Area of metal, square inches A	Radius of gyration squared $R^2 = I/A$	Radius of gyration R	Strength factor Q	External diameter O. D.	Thickness	Weight per foot	Moment of inertia I	Section modulus I/y	Area of metal, square inches A	Radius of gyration squared $R^2 = I/A$	Radius of gyration R	Strength factor Q
.375	.065	.215	.0007939	.004234	.06330	.01254	.1120	.009526	1.500	.120	1.768	.1248	.1664	.5202	.2398	.4897	.3743
.405	.068	.244	.001064	.005252	.07199	.01477	.1215	.01182	1.500	.125	1.835	.1287	.1716	.5400	.2383	.4881	.3860
.405	.095	.314	.001216	.006004	.09252	.01314	.1146	.01351	1.500	.134	1.954	.1354	.1806	.5750	.2355	.4853	.4063
.500	.065	.301	.002148	.008592	.08883	.02418	.1555	.01933	1.500	.135	1.968	.1362	.1815	.5789	.2352	.4850	.4085
.540	.088	.424	.003312	.01227	.1250	.02651	.1628	.02760	1.500	.148	2.137	.1454	.1938	.6286	.2312	.4809	.4361
.540	.119	.535	.003766	.01395	.1574	.02393	.1547	.03138	1.500	.150	2.162	.1467	.1956	.6362	.2306	.4802	.4402
.625	.069	.409	.004729	.01513	.1205	.03924	.1981	.03405	1.660	.095	1.587	.1435	.1729	.4671	.3073	.5543	.3891
.675	.091	.567	.007291	.02160	.1670	.04367	.2090	.04860	1.660	.140	2.272	.1947	.2346	.6685	.2913	.5397	.5278
.675	.126	.738	.008619	.02554	.2173	.03966	.1991	.05746	1.660	.191	2.996	.2418	.2913	.8815	.2743	.5237	.6555
.750	.078	.559	.009421	.02512	.1647	.05721	.2392	.05652	1.660	.382	5.214	.3411	.4110	1.534	.2224	.4716	.9247
.840	.078	.634	.01369	.03261	.1867	.07334	.2708	.07336	1.750	.095	1.679	.1697	.1939	.4939	.3435	.5861	.4363
.840	.109	.850	.01709	.04069	.2503	.06828	.2613	.09156	1.750	.109	1.910	.1900	.2171	.5619	.3381	.5815	.4885
.840	.147	1.087	.02008	.04780	.3200	.06273	.2505	.1076	1.750	.110	1.926	.1914	.2187	.5667	.3377	.5811	.4922
.840	.294	1.714	.02424	.05772	.5043	.04807	.2192	.1299	1.750	.120	2.089	.2052	.2345	.6145	.3339	.5779	.5276
.875	.078	.663	.01566	.03578	.1953	.08016	.2831	.08051	1.750	.125	2.169	.2119	.2422	.6381	.3320	.5762	.5448
1.000	.078	.768	.02418	.04836	.2259	.1070	.3271	.1088	1.750	.134	2.312	.2236	.2555	.6803	.3287	.5733	.5750
1.050	.078	.809	.02831	.05392	.2382	.1189	.3448	.1213	1.750	.135	2.328	.2249	.2570	.6849	.3283	.5730	.5782
1.050	.113	1.130	.03704	.07055	.3326	.1113	.3337	.1587	1.750	.148	2.532	.2410	.2754	.7449	.3235	.5688	.6197
1.050	.154	1.473	.04479	.08531	.4335	.1033	.3214	.1919	1.750	.150	2.563	.2434	.2782	.7540	.3228	.5682	.6259
1.050	.308	2.440	.05792	.1103	.7180	.08068	.2840	.2482	1.875	.095	1.806	.2110	.2251	.5312	.3972	.6302	.5064
1.250	.089	1.103	.05502	.08803	.3246	.1695	.4117	.1981	1.875	.109	2.055	.2367	.2524	.6047	.3913	.6256	.5680
1.315	.089	1.165	.06474	.09847	.3428	.1889	.4346	.2216	1.875	.110	2.073	.2384	.2543	.6099	.3909	.6252	.5722
1.315	.133	1.678	.08734	.1328	.4939	.1769	.4205	.2989	1.875	.120	2.249	.2559	.2730	.6616	.3868	.6219	.6142
1.315	.179	2.171	.1056	.1606	.6388	.1653	.4066	.3614	1.875	.125	2.336	.2644	.2820	.6872	.3848	.6203	.6346
1.315	.358	3.659	.1405	.2136	1.076	.1305	.3613	.4807	1.875	.134	2.491	.2793	.2980	.7329	.3811	.6174	.6704
1.500	.095	1.425	.1039	.1386	.4193	.2479	.4979	.3118	1.875	.135	2.508	.2810	.2997	.7380	.3807	.6170	.6743
1.500	.109	1.619	.1159	.1545	.4763	.2433	.4933	.3477	1.875	.148	2.729	.3016	.3217	.8030	.3756	.6128	.7237
1.500	.110	1.632	.1167	.1556	.4803	.2430	.4930	.3502	1.875	.150	2.763	.3046	.3250	.8129	.3748	.6122	.7311

[20] Book of Standards (National Tube Company) 1913 Edition, pages 58-65.

PROPERTIES OF PIPE—Continued

Strength factor $Q = \frac{\text{foot pounds}}{1000} = \frac{I}{y} \times \frac{27\,000}{1\,000} \times \frac{1}{12} = \frac{9}{2} \frac{I}{\text{O. D.}}$,

y = distance of farthest fiber from axis.

External diameter O. D.	Thickness	Weight per foot	Moment of inertia I	Section modulus I/y	Area of metal, square inches A	Radius of gyration squared $R^2 = I/A$	Radius of gyration R	Strength factor Q
1.900	.109	2.084	.2468	.2598	.6133	.4024	.6344	.5846
1.900	.145	2.717	.3099	.3262	.7995	.3876	.6226	.7340
1.900	.159	2.956	.3322	.3497	.8697	.3820	.6181	.7869
1.900	.200	3.631	.3912	.4118	1.068	.3663	.6052	.9265
1.900	.400	6.408	.5678	.5977	1.885	.3013	.5489	1.345
2.000	.095	1.932	.2586	.2586	.5685	.4548	.6744	.5817
2.000	.109	2.201	.2904	.2904	.6475	.4485	.6697	.6534
2.000	.110	2.220	.2926	.2926	.6531	.4480	.6693	.6584
2.000	.120	2.409	.3144	.3144	.7087	.4436	.6660	.7074
2.000	.125	2.503	.3250	.3250	.7363	.4414	.6644	.7313
2.000	.134	2.670	.3437	.3437	.7855	.4375	.6614	.7732
2.000	.135	2.688	.3457	.3457	.7910	.4371	.6611	.7778
2.000	.148	2.927	.3715	.3715	.8611	.4315	.6569	.8360
2.000	.150	2.963	.3754	.3754	.8718	.4306	.6562	.8447
2.250	.095	2.186	.3741	.3325	.6432	.5816	.7626	.7482
2.250	.100	2.296	.3911	.3477	.6754	.5791	.7610	.7822
2.250	.109	2.492	.4212	.3744	.7332	.5745	.7579	.8423
2.250	.110	2.514	.4245	.3773	.7395	.5740	.7576	.8489
2.250	.120	2.729	.4568	.4061	.8030	.5689	.7543	.9137
2.250	.125	2.836	.4727	.4201	.8345	.5664	.7526	.9453
2.250	.134	3.028	.5006	.4449	.8908	.5619	.7496	1.001
2.250	.135	3.049	.5036	.4476	.8970	.5614	.7493	1.007
2.250	.148	3.322	.5425	.4822	.9773	.5550	.7450	1.085
2.250	.150	3.364	.5483	.4874	.9896	.5541	.7444	1.097
2.375	.130	3.117	.5796	.4881	.9169	.6321	.7951	1.098
2.375	.134	3.207	.5943	.5005	.9434	.6300	.7937	1.126
2.375	.154	3.652	.6657	.5606	1.075	.6196	.7871	1.261
2.375	.166	3.916	.7066	.5951	1.152	.6134	.7832	1.339
2.375	.167	3.938	.7100	.5979	1.158	.6129	.7829	1.345
2.375	.187	4.380	.7748	.6525	1.285	.6028	.7764	1.468
2.375	.190	4.433	.7842	.6604	1.304	.6013	.7754	1.486
2.375	.218	5.022	.8679	.7309	1.477	.5875	.7665	1.644
2.375	.436	9.029	1.311	1.104	2.656	.4937	.7027	2.485
2.500	.095	2.440	.5198	.4158	.7178	.7241	.8510	.9356
2.500	.108	2.759	.5816	.4653	.8116	.7167	.8466	1.047
2.500	.109	2.783	.5863	.4690	.8188	.7161	.8462	1.055
2.500	.110	2.807	.5910	.4728	.8259	.7155	.8459	1.064
2.500	.120	3.050	.6369	.5095	.8972	.7098	.8425	1.146
2.500	.125	3.170	.6594	.5275	.9327	.7070	.8409	1.187
2.500	.134	3.386	.6992	.5594	.9960	.7020	.8378	1.259
2.500	.135	3.409	.7036	.5628	1.003	.7014	.8375	1.266
2.500	.148	3.717	.7592	.6074	1.094	.6942	.8332	1.367
2.500	.150	3.764	.7676	.6141	1.107	.6931	.8325	1.382
2.750	.109	3.074	.7898	.5744	.9044	.8733	.9345	1.292
2.750	.113	3.182	.8152	.5929	.9361	.8708	.9332	1.334
2.875	.183	5.261	1.408	.9798	1.548	.9100	.9540	2.205
2.875	.203	5.793	1.530	1.064	1.704	.8976	.9474	2.394
2.875	.217	6.160	1.611	1.121	1.812	.8890	.9429	2.521
2.875	.226	6.393	1.662	1.156	1.881	.8835	.9400	2.601
2.875	.276	7.661	1.924	1.339	2.254	.8539	.9241	3.012
2.875	.552	13.695	2.871	1.997	4.028	.7126	.8442	4.493
3.000	.095	2.947	.9156	.6104	.8670	1.056	1.028	1.373
3.000	.109	3.365	1.036	.6905	.9900	1.046	1.023	1.554
3.000	.110	3.395	1.044	.6961	.9987	1.046	1.023	1.566
3.000	.116	3.572	1.094	.7297	1.051	1.041	1.020	1.642
3.000	.120	3.691	1.128	.7518	1.086	1.039	1.019	1.691
3.000	.125	3.838	1.169	.7791	1.129	1.035	1.017	1.753
3.000	.134	4.101	1.241	.8277	1.207	1.029	1.014	1.862
3.000	.135	4.130	1.249	.8330	1.215	1.028	1.014	1.874
3.000	.148	4.508	1.352	.9013	1.326	1.019	1.010	2.028
3.000	.150	4.565	1.367	.9116	1.343	1.018	1.009	2.051
3.000	.165	4.995	1.481	.9876	1.470	1.008	1.004	2.222
3.250	.120	4.011	1.447	.8906	1.180	1.226	1.107	2.004
3.500	.120	4.331	1.822	1.041	1.274	1.430	1.196	2.343
3.500	.125	4.505	1.890	1.080	1.325	1.426	1.194	2.430
3.500	.216	7.575	3.017	1.724	2.228	1.354	1.164	3.879
3.500	.218	7.641	3.040	1.737	2.248	1.352	1.163	3.908
3.500	.241	8.388	3.294	1.882	2.467	1.335	1.155	4.235
3.500	.255	8.837	3.443	1.967	2.600	1.324	1.151	4.427
3.500	.289	9.910	3.788	2.164	2.915	1.299	1.140	4.870
3.500	.300	10.252	3.894	2.225	3.016	1.291	1.136	5.007
3.500	.600	18.583	5.993	3.424	5.466	1.096	1.047	7.705
3.750	.120	4.652	2.257	1.203	1.368	1.649	1.284	2.708
3.750	.129	4.988	2.408	1.284	1.467	1.641	1.281	2.890
4.000	.128	5.293	2.921	1.461	1.557	1.876	1.370	3.286
4.000	.134	5.532	3.044	1.522	1.627	1.870	1.368	3.425
4.000	.226	9.109	4.788	2.394	2.680	1.787	1.337	5.386
4.000	.250	10.012	5.200	2.600	2.945	1.766	1.329	5.850
4.000	.318	12.505	6.280	3.140	3.678	1.707	1.307	7.065
4.000	.636	22.850	9.848	4.924	6.721	1.465	1.210	11.08
4.250	.138	6.060	3.772	1.775	1.783	2.116	1.455	3.994
4.500	.134	6.248	4.384	1.948	1.838	2.385	1.544	4.384
4.500	.142	6.609	4.620	2.053	1.944	2.377	1.542	4.620
4.500	.205	9.403	6.393	2.841	2.766	2.311	1.520	6.393
4.500	.237	10.790	7.233	3.214	3.174	2.279	1.510	7.233
4.500	.250	11.347	7.563	3.361	3.338	2.266	1.505	7.563
4.500	.252	11.433	7.613	3.383	3.363	2.264	1.505	7.613
4.500	.255	11.561	7.688	3.417	3.401	2.261	1.504	7.688
4.500	.271	12.240	8.082	3.592	3.600	2.245	1.498	8.082
4.500	.337	14.983	9.610	4.271	4.407	2.181	1.477	9.610
4.500	.674	27.541	15.28	6.793	8.101	1.887	1.374	15.28
4.750	.145	7.131	5.566	2.344	2.098	2.653	1.629	5.273
4.750	.193	9.393	7.185	3.025	2.763	2.600	1.613	6.807
4.750	.334	15.752	11.36	4.783	4.634	2.452	1.566	10.76
5.000	.134	6.963	6.068	2.427	2.048	2.962	1.721	5.461
5.000	.148	7.669	6.645	2.658	2.256	2.945	1.716	5.980
5.000	.152	7.870	6.808	2.723	2.315	2.941	1.715	6.127
5.000	.247	12.538	10.44	4.177	3.688	3.832	1.683	9.399
5.000	.250	12.682	10.55	4.220	3.731	2.828	1.682	9.496
5.000	.288	14.493	11.88	4.751	4.263	2.786	1.669	10.69
5.000	.306	15.340	12.48	4.992	4.512	2.766	1.663	11.23
5.000	.355	17.611	14.05	5.621	5.180	2.712	1.647	12.65
5.000	.710	32.530	22.62	9.047	9.569	2.364	1.537	20.35
5.250	.153	8.328	7.963	3.034	2.450	3.250	1.803	6.826
5.250	.182	9.851	9.315	3.549	2.898	3.215	1.793	7.985
5.250	.241	12.892	11.92	4.542	3.792	3.144	1.773	10.22
5.250	.301	15.909	14.38	5.478	4.680	3.073	1.753	12.33
5.500	.154	8.792	9.248	3.363	2.586	3.575	1.891	7.566
5.500	.228	12.837	13.14	4.780	3.776	3.481	1.866	10.75
5.500	.304	16.870	16.80	6.111	4.962	3.386	1.840	13.75
5.563	.258	14.617	15.16	5.451	4.300	3.526	1.878	12.26
5.563	.293	16.491	16.89	6.073	4.851	3.482	1.866	13.66
5.563	.304	17.074	17.42	6.263	5.023	3.469	1.862	14.09
5.563	.375	20.778	20.67	7.431	6.112	3.382	1.839	16.72
5.563	.750	38.552	33.63	12.09	11.34	2.966	1.722	27.21
6.000	.140	8.762	11.07	3.690	2.577	4.295	2.072	8.302
6.000	.164	10.222	12.81	4.270	3.007	4.261	2.064	9.608
6.000	.165	10.282	12.88	4.294	3.025	4.259	2.064	9.662
6.000	.190	11.789	14.65	4.883	3.468	4.224	2.055	10.99
6.000	.224	13.818	16.98	5.659	4.065	4.177	2.044	12.73
6.000	.275	16.814	20.31	6.770	4.946	4.106	2.026	15.23
6.000	.280	17.105	20.63	6.876	5.032	4.100	2.025	15.47
6.000	.324	19.641	23.34	7.781	5.777	4.040	2.010	17.51
6.625	.169	11.652	17.87	5.395	3.428	5.214	2.283	12.14
6.625	.184	12.657	19.32	5.834	3.723	5.190	2.278	13.13
6.625	.185	12.724	19.42	5.863	3.743	5.188	2.278	13.19
6.625	.245	16.694	25.02	7.554	4.911	5.096	2.257	17.00
6.625	.280	18.974	28.14	8.496	5.581	5.042	2.245	19.12

PROPERTIES OF PIPE—Concluded

Strength factor $Q = \frac{\text{foot pounds}}{1000} = \frac{I}{y} \times \frac{27\,000}{1\,000} \times \frac{1}{12} = \frac{9}{2}\frac{I}{\text{O. D.}}$,

y = distance of farthest fiber from axis.

External diameter O .D.	Thickness	Weight per foot	Moment of inertia I	Section modulus I/y	Area of metal, square inches A	Radius of gyration squared $R^2 = I/A$	Radius of gyration R	Strength factor Q
6.625	.281	19.039	28.23	8.522	5.600	5.041	2.245	19.17
6.625	.288	19.491	28.84	8.707	5.734	5.030	2.243	19.59
6.625	.300	20.265	29.88	9.020	5.961	5.012	2.239	20.29
6.625	.344	23.076	33.57	10.14	6.788	4.946	2.224	22.80
6.625	.383	25.658	36.87	11.13	7.547	4.886	2.210	25.05
6.625	.417	27.648	39.36	11.88	8.133	4.839	2.200	26.73
6.625	.432	28.573	40.49	12.22	8.405	4.817	2.195	27.50
6.625	.864	53.160	66.33	20.02	15.64	4.242	2.060	45.06
7.000	.149	10.902	18.82	5.378	3.207	5.870	2.423	12.10
7.000	.165	12.044	20.70	5.915	3.543	5.843	2.417	13.31
7.000	.174	12.685	21.75	6.213	3.731	5.828	2.414	13.98
7.000	.231	16.699	28.17	8.048	4.912	5.734	2.395	18.11
7.000	.272	19.544	32.58	9.310	5.749	5.667	2.381	20.95
7.000	.275	19.751	32.90	9.400	5.810	5.662	2.380	21.15
7.000	.301	21.535	35.61	10.17	6.335	5.621	2.371	22.89
7.000	.333	23.711	38.85	11.10	6.975	5.570	2.360	24.97
7.000	.362	25.663	41.70	11.92	7.549	5.524	2.350	26.81
7.000	.393	27.731	44.67	12.76	8.157	5.476	2.340	28.72
7.625	.181	14.390	29.34	7.695	4.233	6.931	2.633	17.31
7.625	.301	23.544	46.52	12.20	6.926	6.716	2.592	27.45
7.625	.500	38.048	71.37	18.72	11.19	6.377	2.525	42.12
7.625	.875	63.079	107.5	28.18	18.56	5.791	2.406	63.41
8.000	.158	13.233	29.93	7.484	3.893	7.690	2.773	16.84
8.000	.165	13.807	31.18	7.795	4.061	7.677	2.771	17.54
8.000	.185	15.441	34.69	8.674	4.542	7.639	2.764	19.52
8.000	.186	15.522	34.87	8.717	4.566	7.637	2.763	19.61
8.000	.236	19.569	43.41	10.85	5.756	7.542	2.746	24.42
8.000	.307	25.223	54.98	13.74	7.420	7.410	2.722	30.92
8.000	.322	26.404	57.34	14.33	7.767	7.382	2.717	32.25
8.625	.188	16.940	44.36	10.29	4.983	8.902	2.984	23.14
8.625	.217	19.486	50.69	11.75	5.732	8.843	2.974	26.44
8.625	.264	23.574	60.66	14.07	6.934	8.747	2.958	31.65
8.625	.277	24.696	63.35	14.69	7.265	8.721	2.953	33.05
8.625	.304	27.016	68.87	15.97	7.947	8.666	2.944	35.93
8.625	.311	27.615	70.28	16.30	8.123	8.652	2.941	36.67
8.625	.322	28.554	72.49	16.81	8.399	8.630	2.938	37.82
8.625	.352	31.101	78.41	18.18	9.149	8.571	2.928	40.91
8.625	.354	31.270	78.80	18.27	9.198	8.567	2.927	41.11
8.625	.400	35.137	87.61	20.32	10.34	8.476	2.911	45.71
8.625	.425	37.220	92.27	21.40	10.95	8.428	2.903	48.14
8.625	.487	42.327	103.4	23.99	12.45	8.308	2.882	53.97
8.625	.500	43.388	105.7	24.51	12.76	8.283	2.878	55.16
8.625	.875	72.424	162.0	37.56	21.30	7.604	2.757	84.51
9.000	.167	15.754	45.21	10.05	4.634	9.756	3.123	22.61
9.000	.180	16.955	48.52	10.78	4.988	9.728	3.119	24.26
9.000	.196	18.429	52.55	11.68	5.421	9.694	3.113	26.27
9.000	.250	23.362	65.82	14.63	6.872	9.578	3.095	32.91
9.000	.342	31.624	87.30	19.40	9.302	9.385	3.063	43.65
9.625	.342	33.907	107.6	22.35	9.974	10.79	3.284	50.30
9.625	.500	48.728	149.6	31.09	14.33	10.44	3.231	69.96
10.000	.175	18.363	65.20	13.04	5.402	12.07	3.474	29.34
10.000	.203	21.240	74.99	15.00	6.248	12.00	3.465	33.75
10.000	.208	21.752	76.72	15.34	6.399	11.99	3.463	34.53
10.000	.209	21.855	77.07	15.41	6.429	11.99	3.462	34.68
10.000	.270	28.057	97.75	19.55	8.253	11.84	3.441	43.99
10.000	.283	29.369	102.0	20.41	8.639	11.81	3.437	45.92
10.000	.308	31.881	110.2	22.05	9.378	11.75	3.428	49.60
10.000	.365	37.559	128.4	25.68	11.05	11.62	3.409	57.78
10.750	.279	31.201	125.9	23.42	9.178	13.71	3.703	52.69
10.750	.302	33.699	135.4	25.19	9.913	13.66	3.695	56.67
10.750	.307	34.240	137.4	25.57	10.07	13.64	3.694	57.52
10.750	.348	38.661	154.0	28.65	11.37	13.54	3.680	64.46
10.750	.365	40.483	160.7	29.90	11.91	13.50	3.674	67.28
10.750	.395	43.684	172.5	32.09	12.85	13.42	3.664	72.20
10.750	.424	46.760	183.6	34.16	13.75	13.35	3.654	76.87
10.750	.483	52.962	205.7	38.28	15.58	13.21	3.634	86.12
10.750	.500	54.735	212.0	39.43	16.10	13.16	3.628	88.72
11.000	.185	21.368	91.93	16.71	6.286	14.62	3.824	37.61
11.000	.220	25.329	108.3	19.69	7.451	14.53	3.812	44.29
11.000	.224	25.780	110.1	20.02	7.583	14.52	3.811	45.05
11.000	.290	33.171	140.0	25.46	9.757	14.35	3.788	57.27
11.750	.375	45.557	217.0	36.93	13.40	16.19	4.024	83.10
11.750	.500	60.075	280.1	47.68	17.67	15.85	3.981	107.3
12.000	.194	24.461	125.4	20.90	7.195	17.43	4.175	47.02
12.000	.229	28.788	146.7	24.45	8.468	17.33	4.162	55.02
12.000	.243	30.512	155.1	25.86	8.975	17.29	4.158	58.18
12.000	.244	30.635	155.7	25.96	9.012	17.28	4.157	58.40
12.000	.308	38.460	193.5	32.24	11.31	17.10	4.135	72.55
12.000	.310	38.703	194.6	32.44	11.38	17.09	4.134	72.98
12.000	.375	46.558	231.6	38.60	13.70	16.91	4.112	86.85
12.750	.330	43.773	248.5	38.97	12.88	19.30	4.393	87.69
12.750	.375	49.562	279.3	43.82	14.58	19.16	4.377	98.59
12.750	.500	65.415	361.5	56.71	19.24	18.79	4.335	127.6
13.000	.202	27.610	166.3	25.59	8.122	20.48	4.525	57.57
13.000	.238	32.439	194.3	29.90	9.542	20.37	4.513	67.27
13.000	.247	33.642	201.3	30.96	9.896	20.34	4.510	69.67
13.000	.259	35.243	210.5	32.38	10.37	20.30	4.506	72.85
13.000	.281	38.171	227.2	34.95	11.23	20.23	4.498	78.63
13.000	.310	42.014	248.9	38.30	12.36	20.14	4.488	86.17
13.000	.320	43.335	256.4	39.44	12.75	20.11	4.484	88.74
13.000	.359	48.467	285.0	43.85	14.26	19.99	4.471	98.65
13.000	.361	48.730	286.5	44.07	14.33	19.98	4.470	99.16
14.000	.210	30.928	216.3	30.90	9.098	23.78	4.876	69.53
14.000	.248	36.424	253.4	36.20	10.71	23.65	4.863	81.46
14.000	.250	36.713	255.3	36.47	10.80	23.64	4.862	82.06
14.000	.276	40.454	280.3	40.04	11.90	23.55	4.853	90.09
14.000	.310	45.325	312.5	44.64	13.33	23.44	4.841	100.4
14.000	.328	47.894	329.4	47.05	14.09	23.38	4.835	105.9
14.000	.375	54.568	372.8	53.25	16.05	23.22	4.819	119.8
14.000	.438	63.441	429.5	61.36	18.66	23.01	4.797	138.1
14.000	.500	72.091	483.8	69.11	21.21	22.81	4.776	155.5
15.000	.222	35.038	281.4	37.52	10.31	27.30	5.225	84.43
15.000	.259	40.775	325.9	43.45	11.99	27.17	5.213	97.77
15.000	.260	40.930	327.1	43.61	12.04	27.17	5.212	98.13
15.000	.291	45.714	363.8	48.51	13.45	27.05	5.201	109.1
15.000	.320	50.171	397.7	53.03	14.76	26.95	5.191	119.3
15.000	.375	58.573	461.0	61.46	17.23	26.75	5.172	138.3
15.000	.438	68.119	531.6	70.88	20.04	26.53	5.151	159.5
15.000	.500	77.431	599.3	79.91	22.78	26.31	5.130	179.8
16.000	.234	39.401	360.2	45.02	11.59	31.08	5.575	101.3
16.000	.270	45.359	412.8	51.60	13.34	30.94	5.562	116.1
16.000	.302	50.632	458.9	57.37	14.89	30.81	5.551	129.1
16.000	.330	55.228	498.9	62.36	16.25	30.71	5.541	140.3
16.000	.375	62.579	562.1	70.26	18.41	30.54	5.526	158.1
16.000	.401	66.806	598.1	74.76	19.65	30.44	5.517	168.2
16.000	.500	82.771	731.9	91.49	24.35	30.06	5.483	205.9
17.000	.240	42.959	443.8	52.21	12.64	35.12	5.926	117.5
17.000	.393	69.704	707.2	83.21	20.50	34.49	5.873	187.2
18.000	.245	46.458	538.6	59.85	13.67	39.41	6.278	134.7
18.000	.310	58.568	674.1	74.90	17.23	39.13	6.255	168.5
18.000	.409	76.840	874.8	97.20	22.60	38.70	6.221	218.7
18.000	.500	93.451	1053.	117.0	27.49	38.31	6.190	263.3
19.000	.259	51.840	669.6	70.49	15.25	43.91	6.627	158.6
20.000	.272	57.309	820.3	82.03	16.86	48.66	6.976	184.6
20.000	.375	78.599	1113.	111.3	23.12	48.16	6.940	250.5
20.000	.409	85.577	1208.	120.8	25.17	48.00	6.928	271.8
22.000	.301	69.756	1208.	109.8	20.52	58.87	7.672	247.1
22.000	.400	92.276	1584.	144.0	27.14	58.34	7.638	323.9
24.000	.330	83.423	1719.	143.2	24.54	70.05	8.369	322.3
26.000	.362	99.122	2396.	184.3	29.16	82.18	9.065	414.7
28.000	.396	116.746	3272.	233.7	34.34	95.27	9.760	525.8
30.000	.432	136.421	4386.	292.4	40.13	109.3	10.45	658.0

PIPE COLUMNS[21]

Those parts of a structure that resist thrust or compressive stress are known as columns or struts. Except when comparatively quite short, columns and struts tend to fail by lateral bending or buckling. While apparently similar in this respect to beams, the real stresses in a loaded column are, however, of such an obscure nature that no satisfactory theoretical formula has yet been produced for columns of the proportions commonly used in practice. The only really useful formulae for columns and struts are those based directly upon experimental data.

Radius of Gyration. The radius of gyration is the property of the cross-section of a column that determines its strength. The relation of the radius of gyration, R, to the moment of inertia, I, and area of cross-section, A, is such that it equals the square root of the quotient resulting from dividing the former by the latter, or $R = \sqrt{I \div A}$.

Slenderness Ratio. The strength of a column or strut is most easily expressed in terms of its slenderness ratio, which is the length divided by the least radius of gyration, $\frac{L}{R}$, both being stated in inches.

Strength Columns. The strength of a column or strut depends (1) upon the manner in which the ends are connected to the rest of the structure, whether fixed in direction, hinged, etc., and upon the placing of the loading, whether axial or eccentric; (2) upon the slenderness ratio, $\frac{L}{R}$; (3) upon the area of cross-section, A; and (4) upon the physical properties of the material.

Tables of Safe Loads for Pipe Columns. The tables, pages 64 and 65, give the safe loads in tons of 2000 pounds for Standard, Extra Strong and Double Extra Strong Pipe, computed by the formulae of the New York and Chicago Building Laws.

According to the New York Building Code, the allowable compressive stress per square inch for steel columns with flat ends is given by the formula $S = 15\,200 - 58\frac{L}{R}$, where L is the length of the column and R is the least radius of gyration, both in inches. It further states that no column shall be used whose unsupported length is greater than 120 times its least radius of gyration.

According to the Chicago Building Ordinances the allowable compressive stress per square inch for steel columns shall be determined by the formula $S = 16\,000 - 70\frac{L}{R}$, with a maximum allowable stress of 14 000 pounds per square inch. The length of column is limited to 120 times the least radius of gyration, except in the case of struts for wind bracing, in which case the limit is 150 times the least radius of gyration.

STANDARD PIPE COLUMNS

(Loads in tons of 2000 pounds, based on New York Building Code.)

$S = 15\,200 - 58\,L/R$

S = allowable compressive stress for steel, pounds per square inch; L = length of column in inches; R = least radius of gyration in inches.

Length, feet	SIZE OF PIPE																
	2	2½	3	3½	4	4½	5	6	7	8	9	10	11	12	13	14	15
	THICKNESS																
	.154	.203	.216	.226	.237	.247	.258	.280	.301	.322	.342	.365	.375	.375	.375	.375	.375
40	....	....	....	....	....	....	....	....	.....	24.04	33.53	45.38	55.49	64.44	75.63	84.58	93.53
36	....	....	....	....	....	....	....	.....	19.16	28.02	37.76	49.90	60.12	69.07	80.26	89.21	98.17
33	....	....	....	....	....	....	.....	13.87	21.95	31.00	40.93	53.28	63.60	72.55	83.74	92.69	101.64
30	....	....	....	....	....	....	.....	16.47	24.74	33.99	44.10	56.66	67.08	76.03	87.22	96.17	105.12
27	....	....	....	....	....	.....	11.16	19.06	27.53	36.97	47.27	60.05	70.55	79.51	90.69	99.65	108.60
24	....	....	....	....	.....	9.72	13.55	21.66	30.32	39.96	50.44	63.43	74.03	82.98	94.17	103.12	112.08
22	....	....	....	.....	8.02	11.25	15.15	23.39	32.18	41.95	52.55	65.69	76.35	85.30	96.49	105.44	114.40
20	....	....	.....	6.41	9.49	12.78	16.74	25.12	34.04	43.94	54.66	67.94	78.67	87.62	98.81	107.76	116.71
18	....	....	.....	7.81	10.95	14.30	18.34	26.85	35.90	45.93	56.78	70.20	80.99	89.94	101.13	110.08	119.03
16	....	....	6.27	9.20	12.42	15.83	19.93	28.58	37.76	47.92	58.89	72.46	83.30	92.26	103.45	112.40	121.35
14	....	4.19	7.61	10.60	13.88	17.35	21.52	30.31	39.62	49.90	61.01	74.71	85.62	94.57	105.76	114.72	123.67
13	....	4.81	8.27	11.30	14.61	18.11	22.32	31.17	40.55	50.90	62.06	75.84	86.78	95.73	106.92	115.88	124.83
12	....	5.44	8.94	11.99	15.34	18.88	23.12	32.04	41.48	51.89	63.12	76.97	87.94	96.89	108.08	117.03	125.99
11	2.94	6.07	9.61	12.69	16.07	19.64	23.91	32.90	42.41	52.89	64.18	78.10	89.10	98.05	109.24	118.19	127.15
10	3.42	6.69	10.27	13.39	16.81	20.40	24.71	33.77	43.34	53.88	65.23	79.22	90.26	99.21	110.40	119.35	128.31
9	3.89	7.32	10.94	14.09	17.54	21.17	25.51	34.63	44.27	54.88	66.29	80.35	91.42	100.37	111.56	120.51	129.47
8	4.37	7.94	11.60	14.78	18.27	21.93	26.30	35.50	45.20	55.87	67.35	81.48	92.57	101.53	112.72	121.67	130.62
7	4.84	8.57	12.27	15.48	19.00	22.69	27.10	36.36	46.13	56.87	68.40	82.61	93.73	102.69	113.88	122.83	131.78
6	5.32	9.20	12.94	16.18	19.73	23.45	27.90	37.23	47.06	57.86	69.46	83.74	94.89	103.85	115.04	123.99	132.94
5	5.79	9.82	13.60	16.88	20.46	24.22	28.69	38.09	47.99	58.86	70.52	84.86	96.05	105.00	116.20	125.15	134.10

NOTE—Loads above or to the left of the zigzag line correspond to values of L/R greater than 120.

STANDARD PIPE COLUMNS (Concluded)

(Loads in tons of 2000 pounds, based on Chicago Building Ordinances.)

$S = 16\,000 - 70\,L/R$.

S = allowable compressive stress for steel, pounds per square inch; L = length of column in inches; R = least radius of gyration in inches; Maximum allowable compressive stress = 14 000 pounds per square inch.

Length, feet	SIZE OF PIPE																
	2	2½	3	3½	4	4½	5	6	7	8	9	10	11	12	13	14	15
	THICKNESS																
	.154	.203	.216	.226	.237	.247	.258	.280	.301	.322	.342	.365	.375	.375	.375	.375	.375
40	....	....	....	....	....	....	....	....	.....	19.16	28.77	40.81	51.26	60.68	72.45	81.88	91.30
36	....	....	....	....	....	....	....	.....	15.00	23.96	33.87	46.26	56.85	66.27	78.05	87.47	96.89
33	....	....	....	....	....	....	.....	10.20	18.37	27.57	37.70	50.34	61.05	70.47	82.25	91.67	101.09
30	....	....	....	....	....	....	.....	13.33	21.73	31.17	41.53	54.43	65.24	74.67	86.44	95.87	105.29
27	....	....	....	....	....	.....	8.43	16.46	25.10	34.77	45.35	58.51	69.44	78.86	90.64	100.06	109.49
24	....	....	....	....	.....	7.41	11.32	19.60	28.47	38.37	49.18	62.59	73.64	83.06	94.84	104.26	113.68
22	....	....	....	.....	5.96	9.25	13.24	21.68	30.71	40.78	51.73	65.32	76.43	85.86	97.64	107.06	116.48
20	....	....	.....	4.60	7.73	11.09	15.16	23.77	32.96	43.18	54.28	68.04	79.23	88.65	100.43	109.86	119.28
18	....	....	.....	6.28	9.50	12.94	17.09	25.86	35.20	45.58	56.83	70.76	82.03	91.45	103.23	112.65	122.08
16	....	....	4.96	7.97	11.26	14.78	19.01	27.95	37.45	47.98	59.38	73.48	84.83	94.25	106.03	115.45	124.88
14	....	3.06	6.57	9.65	13.03	16.62	20.93	30.04	39.69	50.38	61.93	76.21	87.62	97.05	108.83	118.25	127.67
13	....	3.81	7.37	10.49	13.91	17.54	21.90	31.08	40.81	51.58	63.21	77.57	89.02	98.45	110.23	119.65	128.85
12	....	4.57	8.18	11.33	14.79	18.46	22.86	32.12	41.94	52.78	64.49	78.93	90.42	99.85	111.62	120.61	128.85
11	2.29	5.32	8.98	12.18	15.68	19.38	23.82	33.17	43.06	53.99	65.76	80.29	91.82	101.24	112.36	120.61	128.85
10	2.86	6.08	9.78	13.02	16.56	20.30	24.78	34.21	44.18	55.19	67.04	81.65	93.22	102.05	112.36	120.61	128.85
9	3.44	6.83	10.59	13.86	17.44	21.22	25.74	35.26	45.30	56.39	68.31	83.01	93.81	102.05	112.36	120.61	128.85
8	4.01	7.59	11.39	14.70	18.33	22.14	26.71	36.30	46.43	57.59	69.59	83.36	93.81	102.05	112.36	120.61	128.85
7	4.58	8.34	12.20	15.54	19.21	23.06	27.67	37.34	47.55	58.79	69.82	83.36	93.81	102.05	112.36	120.61	128.85
6	5.16	9.10	13.00	16.38	20.09	23.98	28.63	38.39	48.48	58.79	69.82	83.36	93.81	102.05	112.36	120.61	128.85
5	5.73	9.86	13.81	17.23	20.98	24.90	29.59	39.07	48.48	58.79	69.82	83.36	93.81	102.05	112.36	120.61	128.85

NOTE—Loads above or to the left of the zigzag line correspond to values of L/R greater than 120.

[21] Book of Standards (National Tube Company) 1913 Edition, pages 244-249.

EXTRA STRONG PIPE COLUMNS

(Loads in tons of 2000 pounds, based on New York Building Code.)

$S = 15\,200 - 58\,L/R$

S = allowable compressive stress for steel, pounds per square inch; L = length of column in inches; R = least radius of gyration in inches.

Length, feet	SIZE OF PIPE 2	2½	3	3½	4	4½	5	6	7	8	9	10	11	12	13	14	15
	THICKNESS .218	.276	.300	.318	.337	.355	.375	.432	.500	.500	.500	.500	.500	.500	.500	.500	.500
40	....	....	.....	.....	.....	.....	.....	.....	.....	35.27	47.18	60.59	72.52	84.45	99.36	111.29	123.23
36	....	....	.....	.....	.....	.....	.....	.....	29.53	41.44	53.36	66.77	78.70	90.63	105.54	117.47	129.41
33	....	....	.....	.....	.....	.....	.....	19.90	34.16	46.07	57.99	71.40	83.33	95.26	110.18	122.11	134.04
30	....	....	.....	.....	.....	.....	.....	23.90	38.79	50.70	62.62	76.04	87.97	99.90	114.81	126.75	138.68
27	....	....	.....	.....	.....	.....	15.22	27.90	43.42	55.33	67.25	80.67	92.60	104.53	119.45	131.38	143.32
24	....	....	.....	.....	.....	13.10	18.69	31.89	48.04	59.96	71.88	85.30	97.23	109.17	124.08	136.02	147.95
22	....	....	.....	.....	10.65	15.29	21.01	34.56	51.13	63.05	74.97	88.39	100.32	112.25	127.17	139.11	151.04
20	....	....	.....	8.36	12.72	17.48	23.32	37.23	54.21	66.13	78.06	91.48	103.41	115.34	130.26	142.20	154.13
18	....	....	.....	10.32	14.80	19.67	25.63	39.89	57.30	69.22	81.15	94.57	106.50	118.43	133.35	145.29	157.22
16	....	....	8.14	12.28	16.88	21.86	27.95	42.56	60.38	72.31	84.23	97.66	109.59	121.52	136.44	148.38	160.31
14	....	5.25	9.99	14.24	18.95	24.05	30.26	45.22	63.47	75.39	87.32	100.74	112.68	124.61	139.53	151.47	163.41
13	....	6.09	10.91	15.22	19.99	25.14	31.42	46.55	65.01	76.94	88.87	102.29	114.22	126.16	141.08	153.01	164.95
12	....	6.94	11.84	16.20	21.03	26.24	32.57	47.89	66.55	78.48	90.41	103.83	115.77	127.70	142.62	154.56	166.50
11	3.85	7.79	12.76	17.18	22.07	27.33	33.73	49.22	68.09	80.02	91.95	105.38	117.31	129.25	144.17	156.10	168.04
10	4.52	8.64	13.68	18.16	23.11	28.43	34.89	50.55	69.64	81.56	93.50	106.92	118.86	130.79	145.71	157.65	169.59
9	5.19	9.49	14.61	19.14	24.15	29.52	36.04	51.88	71.18	83.11	95.04	108.47	120.40	132.34	147.26	159.19	171.13
8	5.86	10.34	15.53	20.12	25.19	30.61	37.20	53.22	72.72	84.65	96.58	110.01	121.95	133.88	148.80	160.74	172.68
7	6.53	11.19	16.46	21.10	26.23	31.71	38.35	54.55	74.26	86.19	98.13	111.56	123.49	135.43	150.35	162.29	174.22
6	7.20	12.03	17.38	22.08	27.26	32.80	39.51	55.88	75.80	87.74	99.67	113.10	125.04	136.97	151.89	163.83	175.77
5	7.87	12.88	18.30	23.06	28.30	33.90	40.67	57.21	77.35	89.28	101.22	114.64	126.58	138.52	153.44	165.38	177.31

NOTE—Loads above or to the left of the zigzag line correspond to values of L/R greater than 120.

EXTRA STRONG PIPE COLUMNS—(Concluded)

(Loads in tons of 2000 pounds, based on Chicago Building Ordinances.)

$S = 16\,000 - 70\,L/R$

S = allowable compressive stress for steel, pounds per square inch; L = length of column in inches; R = least radius of gyration in inches; Maximum allowable compressive stress = 14 000 pounds per square inch.

Length, feet	SIZE OF PIPE 2	2½	3	3½	4	4½	5	6	7	8	9	10	11	12	13	14	15
	THICKNESS .218	.276	.300	.318	.337	.355	.375	.432	.500	.500	.500	.500	.500	.500	.500	.500	.500
40	....	....	.....	.....	.....	.....	.....	.....	.....	27.60	40.14	54.25	66.80	79.36	95.06	107.62	120.18
36	....	....	.....	.....	.....	.....	.....	.....	22.52	35.05	47.59	61.71	74.26	86.82	102.52	115.08	127.64
33	....	....	.....	.....	.....	.....	.....	14.16	28.11	40.64	53.18	67.30	79.85	92.41	108.11	120.67	133.23
30	....	....	.....	.....	.....	.....	.....	18.99	33.69	46.23	58.77	72.89	85.45	98.00	113.70	126.27	138.83
27	....	....	.....	.....	.....	.....	11.21	23.81	39.28	51.81	64.36	78.48	91.04	103.60	119.30	131.86	144.42
24	....	....	.....	.....	.....	9.74	15.39	28.64	44.86	57.40	69.95	84.07	96.63	109.19	124.89	137.45	150.02
22	....	....	.....	.....	7.68	12.38	18.19	31.86	48.58	61.13	73.68	87.80	100.36	112.92	128.62	141.18	153.75
20	....	....	.....	5.78	10.19	15.02	20.98	35.07	52.31	64.85	77.40	91.53	104.09	116.65	132.35	144.91	157.48
18	....	....	.....	8.14	12.69	17.66	23.77	38.29	56.03	68.58	81.13	95.26	107.82	120.38	136.08	148.64	161.21
16	....	....	6.29	10.51	15.20	20.31	26.56	41.51	59.75	72.30	84.86	98.98	111.54	124.11	139.81	152.37	164.94
14	....	3.69	8.52	12.87	17.71	22.95	29.35	44.72	63.48	76.03	88.58	102.71	115.27	127.84	143.54	156.10	168.67
13	....	4.71	9.64	14.06	18.96	24.27	30.75	46.33	65.34	77.89	90.45	104.58	117.14	129.70	145.40	157.97	170.43
12	....	5.74	10.75	15.24	20.22	25.59	32.15	47.94	67.20	79.75	92.31	106.44	119.00	131.56	147.27	159.44	170.43
11	2.91	6.76	11.87	16.42	21.47	26.91	33.54	49.55	69.06	81.61	94.17	108.30	120.87	133.43	148.44	159.44	170.43
10	3.72	7.79	12.98	17.60	22.72	28.23	34.94	51.16	70.92	83.48	96.04	110.17	122.73	134.70	148.44	159.44	170.43
9	4.53	8.81	14.09	18.79	23.98	29.55	36.33	52.76	72.78	85.34	97.90	112.03	123.70	134.70	148.44	159.44	170.43
8	5.34	9.83	15.21	19.97	25.23	30.88	37.73	54.37	74.64	87.20	99.76	112.70	123.70	134.70	148.44	159.44	170.43
7	6.15	10.86	16.32	21.15	26.48	32.20	39.12	55.98	76.51	89.06	100.33	112.70	123.70	134.70	148.44	159.44	170.43
6	6.96	11.88	17.44	22.33	27.74	33.52	40.52	57.59	78.34	89.34	100.33	112.70	123.70	134.70	148.44	159.44	170.43
5	7.77	12.91	18.55	23.52	28.99	34.84	41.92	58.83	78.34	89.34	100.33	112.70	123.70	134.70	148.44	159.44	170.43

NOTE—Loads above or to the left of the zigzag line correspond to values of L/R greater than 120.

DOUBLE EXTRA STRONG PIPE COLUMNS

(Loads in tons of 2000 pounds, based on New York Building Code.)

$S = 15\,200 - 58\,L/R$.

S = allowable compressive stress for steel, pounds per square inch; L = length of column in inches; R = least radius of gyration in inches.

Length, feet	Size of pipe 2	2½	3	3½	4	4½	5	6	7	8
	Thickness .436	.552	.600	.636	.674	.710	.750	.864	.875	.875
40	....	....	.....	.....	.....	.....	.....	.....	.....	54.36
36	....	....	.....	.....	.....	.....	.....	.....	44.42	65.12
33	....	....	.....	.....	.....	.....	.....	31.65	52.47	73.18
30	....	....	.....	.....	.....	.....	.....	39.58	60.52	81.25
27	....	....	.....	.....	.....	.....	24.32	47.51	68.57	89.32
24	....	....	.....	.....	.....	20.74	31.19	55.43	75.62	97.38
22	....	....	.....	.....	16.41	25.07	35.77	60.72	81.99	102.76
20	....	....	.....	12.43	20.52	29.40	40.36	66.00	87.35	108.14
18	....	....	.....	16.30	24.62	33.74	44.94	71.28	92.72	113.51
16	....	.....	12.47	20.16	28.73	38.07	49.52	76.57	98.09	118.89
14	....	7.37	16.11	24.03	32.83	42.40	54.11	81.85	103.45	124.27
13	....	9.03	17.93	25.96	34.89	44.57	56.40	84.50	106.14	126.96
12	....	10.69	19.74	27.89	36.94	46.73	58.69	87.14	108.82	129.65
11	5.72	12.35	21.56	29.83	38.99	48.90	60.98	89.78	111.50	132.33
10	7.03	14.01	23.38	31.76	41.04	51.06	63.27	92.42	114.19	135.02
9	8.35	15.67	25.19	33.69	43.10	53.23	65.56	95.06	116.87	137.71
8	9.66	17.33	27.01	35.62	45.15	55.40	67.85	97.71	119.55	140.40
7	10.98	18.99	28.83	37.56	47.20	57.56	70.15	100.35	122.24	143.09
6	12.29	20.65	30.64	39.49	49.25	59.73	72.44	102.99	124.92	145.78
5	13.61	22.31	32.46	41.42	51.31	61.89	74.73	105.63	127.60	148.47

NOTE—Loads above or to the left of the zigzag line correspond to value of L/R greater than 120.

(Loads in tons of 2000 pounds, based on Chicago Building Ordinances.)

$S = 16\,000 - 70\,L/R$.

(S, L, R, same as above.)

Maximum allowable compressive stress = 14 000 pounds per square inch.

Length, feet	Size of pipe 2	2½	3	3½	4	4½	5	6	7	8
	Thickness .436	.552	.600	.636	.674	.710	.750	.864	.875	.875
40	....	....	.....	.....	.....	.....	.....	.....	.....	40.64
36	....	....	.....	.....	.....	.....	.....	.....	31.86	53.61
33	....	....	.....	.....	.....	.....	.....	19.87	41.57	63.35
30	....	....	.....	.....	.....	.....	.....	29.43	51.29	73.08
27	....	....	.....	.....	.....	.....	16.05	39.00	61.00	82.82
24	....	....	.....	.....	.....	13.81	24.35	48.57	70.72	92.55
22	....	....	.....	.....	10.31	19.04	29.88	54.94	77.19	99.04
20	....	....	.....	7.13	15.27	24.27	35.41	61.32	83.67	105.53
18	....	....	.....	11.79	20.22	29.50	40.94	67.70	90.15	112.02
16	....	.....	8.65	16.46	25.17	34.73	46.47	74.08	96.63	118.51
14	....	4.17	13.03	21.12	30.13	39.95	52.00	80.46	103.10	125.00
13	....	6.17	15.22	23.45	32.61	42.57	54.77	83.64	106.34	128.25
12	....	8.18	17.42	25.78	35.08	45.18	57.54	86.83	109.58	131.49
11	3.78	10.18	19.61	28.12	37.56	47.80	60.30	90.02	112.82	134.74
10	5.37	12.18	21.80	30.45	40.04	50.41	63.07	93.21	116.06	137.98
9	6.96	14.19	24.00	32.78	42.52	53.02	65.83	96.40	119.29	141.23
8	8.55	16.19	26.19	35.11	44.99	55.64	68.60	99.59	122.53	144.47
7	10.13	18.20	28.38	37.45	47.47	58.25	71.36	102.78	125.77	147.72
6	11.72	20.20	30.57	39.78	49.95	60.87	74.13	105.97	129.01	149.13
5	13.31	22.21	32.77	42.11	52.42	63.48	76.89	109.15	129.89	149.13

MECHANICAL PROPERTIES OF SOLID AND TUBULAR BEAMS[22]

All those parts of a structure, such as a simple lever, an automobile axle, or a trolley pole, which have to resist bending actions are known as beams.

The bending actions upon a beam give rise to both stresses and deformations, whose precise nature will of course depend upon the manner of support and the nature of the loading. These will be treated, in what follows, for straight solid and tubular beams having a uniform cross-section throughout their lengths.

Tensile and Compressive Stresses In Beams. The principal stresses in a loaded beam are tension and compression. These are illustrated in Fig. 35 for the case of a beam supported at the ends and loaded at the middle. In this case the lower longitudinal fibers are subjected to tensile stress, while the upper fibers are subjected to compressive stress. The former will, therefore, lengthen and the latter shorten to an extent that will depend upon the amount of the loading. Within the elastic limit of the material the lengthening or shortening of any fiber is directly proportional to its distance from the neutral surface, JJ.

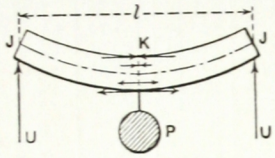


Fig. 35

For steel, and other similar elastic materials not stressed beyond the elastic limit, the *neutral surface* JJ, will always pass through the centers of gravity of the different cross sections. This neutral surface will of course always divide the beam longitudinally into two parts, one of which is subjected to tensile stress and the other to compressive stress. The stresses on the individual fibers of a loaded beam are proportional to their distances from the neutral surface, when all stresses are less than the elastic limit of the material. There is of course no stress upon the fibers lying in the neutral surface, this being the place where the stress passes from tension on one side to compression on the other.

While selecting a value for the working fiber stress, when applying the formulae given in the table, pages 68 and 69, of the Properties of Solid and Tubular Beams, it should be remembered (1) that the fiber of a beam that is subjected to the greatest stress is the one that lies at the greatest distance from the neutral surface, and (2) that this most remote fiber in practice should never be stressed beyond a certain fraction of the elastic limit of the material, the value of the fraction depending upon the nature and frequency of the loading. See pages 70 and 71.

Shearing Stress in Beams. Every beam when loaded is subjected to a transverse stress that tends to shear the beam across, as illustrated at section YY of Fig. 36. The *vertical shear*, s, for any section of a beam is the algebraic sum of all the external vertical forces on either side of that section, upward forces, or reactions, being considered as positive, and downward forces or loads as negative to the left of the section. To the right of the section the algebraic signs are reversed. When s is positive, as at section YY, Fig. 36, the part of the beam to the left of the section tends to slide upward with respect to the part to the right, and when s is negative the left-hand part tends to slide downward with respect to the right-hand part.

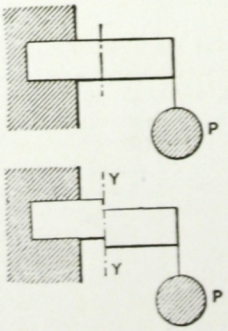


Fig. 36

In most cases the shearing action may be ignored for steel beams, especially for those having comparatively bulky cross sections, such as tubes with sufficiently thick walls relative to their diameters. When, however, the beam is very short, or the loading is quite close to a support, or the web is comparatively thin, then the shearing stress may become of equal or even greater importance than the tension or compression in the beam, in which case it should be taken into consideration.

In the table, pages 68 and 69, of the Properties of Solid and Tubular Beams, the maximum numerical values of the shearing stress will be found tabulated for the different kinds of beam support and loading. The locations of these maximum shears are also given.

[22] Book of Standards (National Tube Company) 1913 Edition, pages 250-256.

Elastic Curve. Since the materials of which beams are constructed are more or less elastic, a beam under load will assume a curved form. The nature of this curve will of course depend upon the manner of support and loading.

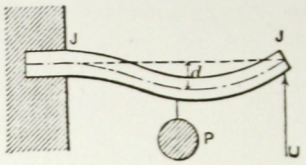


Fig. 37

Fig. 37 shows in a general way the curved form assumed by a beam that is fixed at one end, supported at the other, and loaded at the middle point of its length. The curved line JJ assumed by the neutral axis of the beam, the material not being stressed beyond the elastic limit, is known as the elastic curve. This curve is of the greatest importance in the theoretical discussion of beams.

Elastic Deflection of Beams. The greatest departure of the elastic curve of a loaded beam from the position of the neutral surface when the beam is in an unloaded condition is known as the elastic deflection of the beam. This is shown as d in Fig. 37, and is also represented by the same letter in the different formulae of the table, pages 68 and 69, of the Properties of Solid and Tubular Beams. It is to be understood, of course, that these formulae apply only to beams of uniform cross section and when the most strained fiber of the beam is not stressed beyond the elastic limit of the material.

Reactions of Supports. Two kinds of external forces act upon a beam. These are the loads which tend to move the beam bodily downward and the reactions of the supports which oppose this tendency. Thus, in Fig. 38, the load P acting downward, because of the rigidity of the beam, will be carried to the supports, and will rest upon them jointly. The portion of the load, in this case, carried by the left support, will be $\frac{l-x}{l}P$. The reaction offered by that support, then, will be $U_1 = \frac{l-x}{l}P$, and similarly that carried by the right-hand support will be $U_2 = \frac{x}{l}P$.

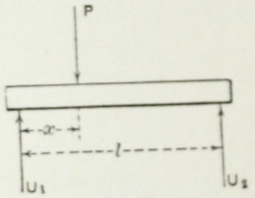


Fig. 38

It is a fundamental principle of mechanics that the sum of the reactions must equal the sum of the loading, or, in the case of the simple beam shown in Fig. 38, $U_1 + U_2 = P$.

In the table of the Properties of Solid and Tubular Beams, pages 68 and 69, the reactions, designated by U, are given for the different kinds of support and loading, and are expressed in the same unit as the loading.

It should be noted that these formulae assume that the reactions act in directions that are parallel to the action of the loading, that is to say, in Fig. 38, the forces U_1, U_2, and P all act in parallel directions.

When a simple beam is subjected at the same time to both uniform and concentrated loads, the reaction may be obtained by taking the sum of the respective reactions due to the uniform load and to each concentrated load.

Bending Moment. The chief action of the external forces upon a beam is most easily expressed as a bending moment, which is the tendency of the external forces to produce rotation of the beam around any of its sections. Thus in Fig. 39, the force P, acting downward at the free end, will tend to cause a bodily rotation of the beam in a downward direction about the section KK, at the fixed end.

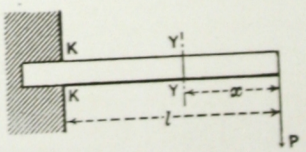


Fig. 39

This tendency to rotate is measured by the force, P, multiplied by the *lever arm*, l, the result, Pl, being the bending moment at the section KK. Similarly, the bending moment at any other section YY will be Px. A bending moment is commonly expressed in inch pounds, the lever arm being stated in inches and the force in pounds.

Considering the portion of a beam that lies to the left of any section, bending moments that tend to cause rotation in a clockwise direction are taken as positive, while those that tend to cause rotation in the opposite direction are taken as negative. For that portion that lies to the right of any section, bending moments that tend to cause rotation in a clockwise

direction are negative, while those that tend to cause rotation in the opposite direction are positive.

The bending moment at any section of a beam is equal to the algebraic sum of the moments of all the external forces on either side of that section.

In case the force P does not act in a direction at right angles to the beam, then the lever arm is to be taken as the perpendicular or shortest distance from the section considered to the line of action of the force. Thus, in Fig. 40, the lever arm is $x = l \sin a$ for the fixed end of the inclined beam, and the corresponding bending moment will be $Pl \sin a$, a being the angle that the line of action of the loading, or other force, makes with the axis of the beam.

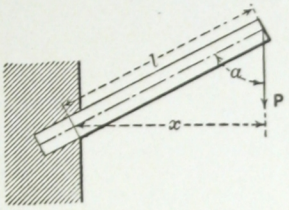


Fig. 40

The bending moments of the table of the Properties of Solid and Tubular Beams, pages 68 and 69, are expressed in inch pounds, and assume that the direction of loading is at right angles to the direction of the beam when in its unloaded condition.

Resisting Moment. The strength of a beam to resist bending action is known as its resisting moment. Thus, in Fig. 41, which represents a beam fixed at one end and loaded at the other, the external force P will evidently give rise to stresses that are held in equilibrium by the internal forces shown. These internal resisting forces, shown in this case for section KK, are due to the tensile strength of the material of the beam lying above the neutral surface JJ, and to the compressive strength of the material lying below JJ. The beam in this case tends to rotate downward about the center of gravity of the section KK, and this tendency is precisely counteracted by the internal forces shown. It is evident that the bending moment Pl, Fig. 41, must equal the sum of the individual moments of each of the internal resisting forces shown, all lever arms being measured from the center of gravity of section KK. In works on mechanics it is shown that this sum, or the total resisting moment, is, for steel not stressed beyond the elastic limit,

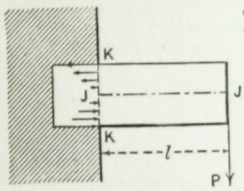


Fig. 41

$$M_r = fZ = f\frac{I}{y}, \qquad (1)$$

where M_r = resisting moment in inch pounds;
f = stress on farthest fiber from neutral surface JJ, in pounds per square inch;
I = moment of inertia of cross section;
y = distance of farthest fiber from neutral surface JJ;
Z = section modulus = I/y.

Moment of Inertia, I, and Section Modulus, Z. These are the properties of the cross section that determine respectively the elasticity and strength of beams. By referring to the table of the Properties of Solid and Tubular Beams, pages 68 and 69, it will be observed that every deflection formula contains as a factor the reciprocal of the moment of inertia of cross section, I, and that every formula for the strength of beams contains as a factor the section modulus, Z. Other things being equal, then, the stiffness of beams will be proportional to their moments of inertia of cross section, while the strengths will be proportional to their section moduli.

These two properties of the cross sections of beams are, therefore, of the greatest importance in the practical application of mechanics to all parts of structures that are subjected to bending actions. The relation of these two properties is such that the value of the section modulus can be obtained by dividing the corresponding moment of inertia by the distance of the farthest fiber from the neutral axis, or

$$Z = \frac{I}{y}. \qquad (2)$$

These properties of the cross section of pipe can be obtained from the table of properties, pages 61, 62 and 63. For the properties of cross sections other than circular see tables, pages 69 and 70.

Strength of Beams. In order that a beam for any kind of support and loading may have sufficient strength, the following conditions must be satisfied:

1. The resisting moment due to the internal longitudinal stresses at any section must equal the bending moment at that section due to the external forces, or

$$fZ = f\frac{I}{y} = M. \qquad (3)$$

2. The resisting shear due to the internal transverse stresses at any section must equal the transverse shear at that section due to the external forces, or

$$f_s A = S, \qquad (4)$$

where M = bending moment in inch pounds;
I = moment of inertia of cross section;
Z = section modulus;
y = distance from farthest fiber to neutral axis in inches;
A = area of cross section in square inches;
f = safe working fiber stress in pounds per square inch;
f_s = safe working shearing stress in pounds per square inch;
S = shearing force in pounds.

Comparative Strength of Beams. The strength of a beam is measured by the load that it can carry when the most strained fiber is stressed to the safe working strength of the material. An examination of the beam formulae, pages 68 and 69, will show, for well-proportioned beams, where the tendency to shear, crimp, or buckle is kept subordinate, that the strength of beams for any kind of support and loading will vary (1) directly as the safe working fiber stress of the material, f_s, (2) directly as the section modulus, Z, and (3) inversely as the length of beam, l.

It is apparent, then, that for similar beams of given material, length, and weight, the one which has the greatest section modulus, Z, will be the strongest. For example, the strength of a tubular beam which is 4 inches diameter by ½ inch wall, as compared with that of a similar solid round beam of the same length, weight, and manner of support and loading, will be as follows: The weight of the tubular beam is 18.69 pounds per foot. The diameter of a solid round beam of the same weight is 2.65 inches. The respective section moduli are, then, 4.30 and 1.83. This tubular beam will, then, be theoretically 2.4 times as strong as a similar solid round beam of the same length and weight.

It should be remembered that for extreme cases, where beams tend to fail by shearing, crimping, or lateral buckling, the above simple relations do not strictly apply. For well-proportioned beams, however, these laws apply with sufficient accuracy for practical purposes, irrespective of the manner of support and loading.

Comparative Stiffness of Beams. The stiffness of a beam is indicated by the load that it can carry with a given deflection. An examination of the beam formulae, pages 68 and 69, will show that the stiffness of a beam, when stressed within the elastic limit of the material, for any kind of support and loading, varies (1) directly as the modulus of elasticity of the material, E, (2) directly as the moment of inertia of cross section, I, and (3) inversely as the cube of the length of beams, P.

Other things being equal, then, the stiffness of beams is directly proportional to their moments of inertia of cross section, I. For example, the above tubular beam, whose strength was shown to be 2.4 times that of a similar solid round beam of the same length, weight, and manner of support and loading, will be found to be 3.5 times as stiff, since their respective moments of inertia of cross section are as 8.59 to 2.42.

Sections Giving Minimum Weight of Beams for a Given Strength or Stiffness. For material, such as steel, which has practically the same physical properties in tension as in compression, the most economical forms of beam cross section are as follows:

1. For *vertical loading only*, that is to say, for loading in a single direction, a beam of given length will have a minimum weight for a given strength or stiffness when it has the "I" section shown in Fig. 42. This form of cross section permits of the most advantageous disposition of the material to resist stress for loading in a single direction, because for this condition both the moments of inertia of cross section, I, and the section modulus, Z, can be made a maximum.

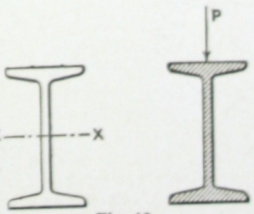


Fig. 42

When designing beams of this character it should be remembered, however, that sufficient material must be put in the web to resist the greatest shear, and that the width of the flange in compression must be sufficient to prevent lateral buckling. Sufficient material must also be put into the web to prevent crushing or buckling of the web underneath the loading and at the supports.

2. For *vertical and horizontal loading*, that is to say, for loading in two directions at right angles to each other, a beam of given length will have a minimum weight for a given strength or stiffness when it has the hollow rectangular section shown in Fig. 45. This form of cross section permits of the most advantageous disposition of the material to resist stresses, for the conditions assumed, since, for this form of beam, the moments of inertia, I, and the section moduli, Z, for a given sectional area, can be made a maximum for both the vertical and horizontal bending actions. When these two actions are equal the cross section should of course be a hollow square.

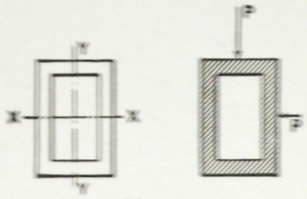


Fig. 45

3. For *equal loading in any direction*, a beam of given length will have a minimum weight for a given strength or stiffness when it has the tubular section shown in Fig. 44. The ordinary tubular form of beam permits of the most advantageous disposition of the material to resist stresses for the conditions assumed, since for the circular section the moment of inertia of cross section, I, and the section modulus, Z, can be made a maximum for loading in all directions around the beam.

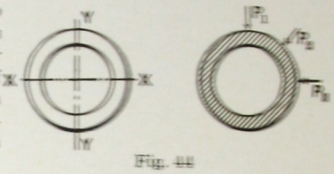


Fig. 44

It is evident that the cylindrical tubular beam will approximate closely to a hollow square beam with respect to strength and stiffness for equal loading in directions at right angles to each other; also, that the hollow oval section will give results approximating closely to those of the hollow rectangular section, Fig. 45.

TABLE OF THE MECHANICAL PROPERTIES OF SOLID AND TUBULAR BEAMS OF UNIFORM CROSS SECTION [23]

This table of the mechanical properties of beams is based upon the assumptions: (1) that the beam is straight when in its unloaded condition; (2) that it has a uniform cross section from end to end; and (3) that the directions of the loading and reactions lie in the same plane and are at right angles to the axis of the beam when in its unloaded condition.

All the formulæ contained in this table of the properties of beams have been calculated anew, because it was desired to eliminate any errors and misprints in the data on beams as found in the different standard works on mechanics.

Notation. In this table of the mechanical properties of beams the following notation is used:

A = area of cross section of beam in square inches. For a hollow or tubular beam, the area of the actual wall cross section must be used.

D = diameter of a solid round beam, in inches, or the outside diameter of a tubular beam.

d = greatest deflection of a beam, in inches, or the greatest deviation from straightness when the beam is subjected to a given loading.

E = modulus of elasticity of the material in pounds. The value of E is approximately 29 000 000 for steel tubing, as obtained by experiments on long tubular beams.

f = fiber stress in pounds per square inch on the most strained fiber of the beam.

f_s = shearing stress in pounds per square inch of cross section of the beam.

I = moment of inertia of cross section of the beam.
Values of I for pipe can be obtained from the table of properties, pages 61, 62 and 63. For sections that are not round see table pages 69 and 70.

J = polar moment of inertia. For circular sections: $J = 2\,I$.

l = length of beam in inches.

M = bending moment in inch pounds due to the loading on the beam.
The greatest value of M and its location, for each style of beam, support and loading, is tabulated to the left and shown on the moment diagram to the right, immediately underneath the figure of the beam.

M_r = resisting moment of the beam cross section in inch pounds $= fZ$.

P = pressure in pounds due to a load or force acting at right angles to the axis of a beam.

R = radius of gyration of cross section in inches $= \sqrt{I \div A}$.
Values of R for pipe can be obtained from the table of properties, pages 61, 62 and 63. For sections that are not round see table, pages 69 and 70.

S, S_1, S_2 = vertical shearing forces in pounds acting on the beam, due to the loading.

U, U_1, U_2 = reactions of the supports of a beam in pounds.

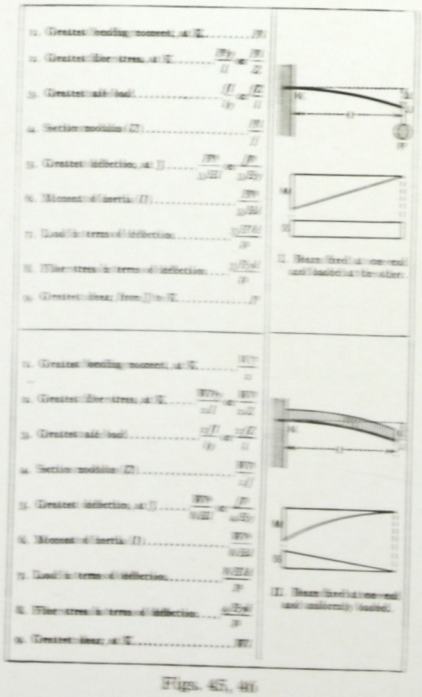
W = weight of a beam in pounds per lineal inch, also weight of a uniformly distributed load in pounds per lineal inch.

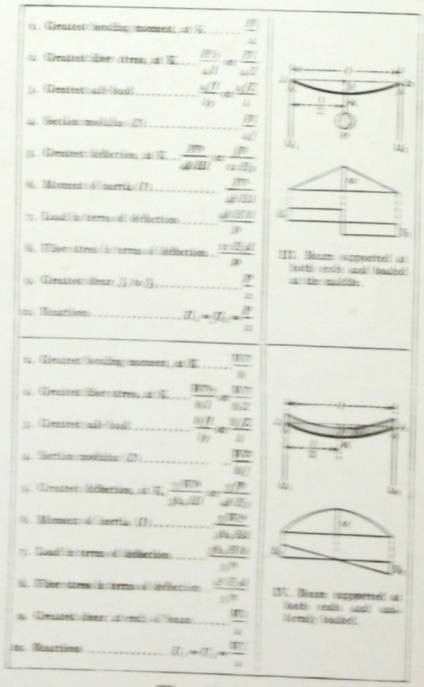
y = distance from neutral axis of beam to the most distant fiber in inches.

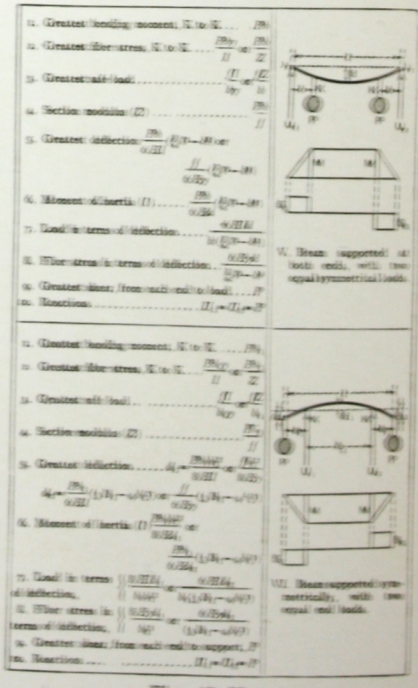
Z = section modulus, or $I \div y$.
Values of Z for pipe are given in the table of properties, pages 61, 62 and 63. For sections that are not round see table, pages 69 and 70.

[23] Book of Standards (National Tube Company) 1913 Edition, pages 256-267.

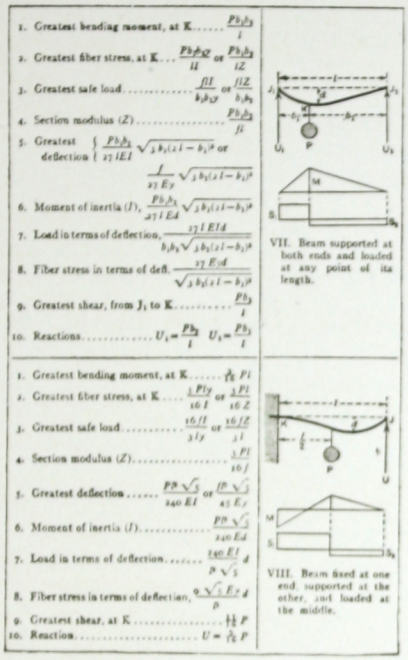
PROPERTIES OF SOLID AND TUBULAR BEAMS


Figs. 45, 46

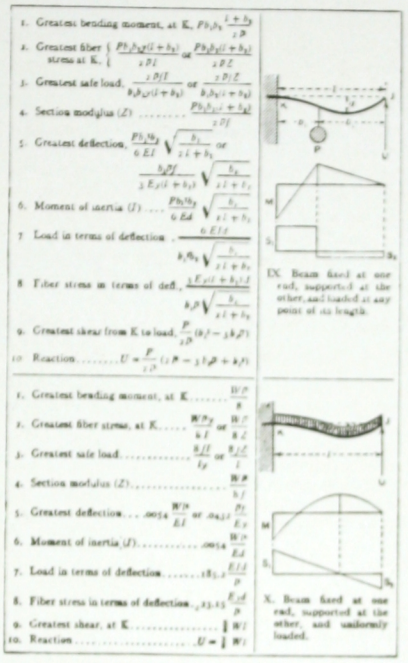

Figs. 47, 48


Figs. 49, 50

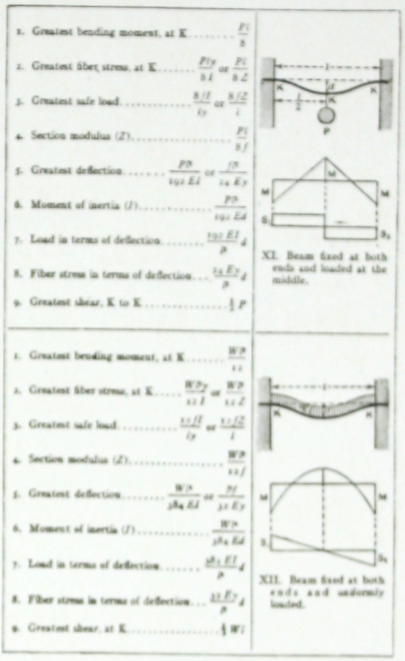
PROPERTIES OF SOLID AND TUBULAR BEAMS—Concluded



Figs. 51, 52

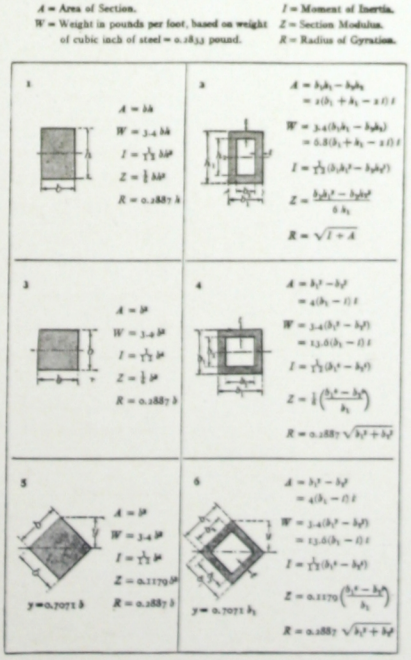


Figs. 53, 54

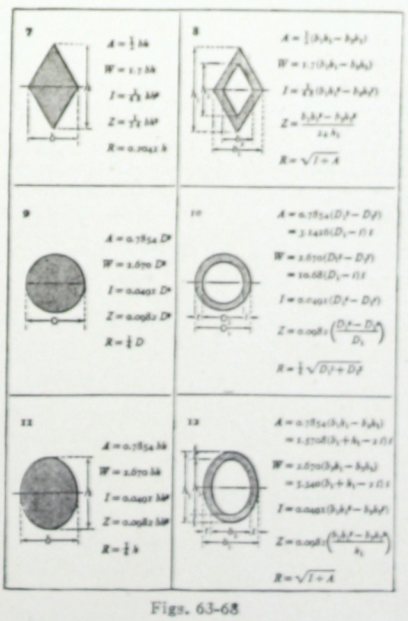


Figs. 55, 56

PROPERTIES OF BEAMS AND COLUMN SECTIONS

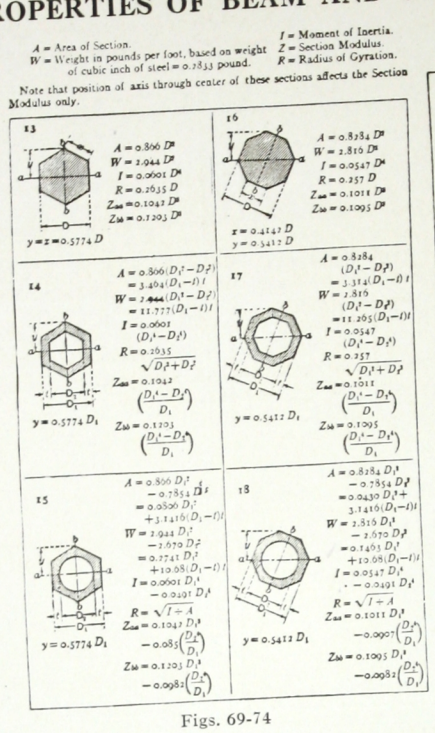


Figs. 57-62

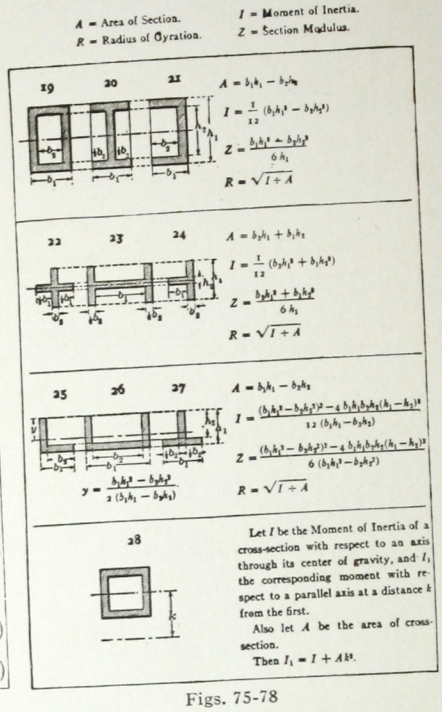


Figs. 63-68

PROPERTIES OF BEAM AND COLUMN SECTIONS—Concluded



Figs. 69-74



Figs. 75-78

SAFETY FACTORS AND SAFE WORKING FIBER STRESSES[24]

Each member of a mechanical structure should be capable of resisting the greatest straining action to which it can ordinarily be subjected when in use. The designer should, therefore, consider under what conditions the straining actions are greatest. When these actions are of a variable character, it is of the utmost importance to take into consideration the effects of this variation upon the endurance of the material. For example, a member may fail under a straining action that causes stresses which fluctuate, or which alternate repeatedly from tension to compression, when the same straining action would be successfully resisted under the conditions of steady loading.

Margin of Security. It is apparent that the working load on a member of a mechanical structure should be less than the calculated breaking load for that member, in order to allow for inaccuracies, deterioration, and probable contingencies, and thus provide a margin of security. It is customary, therefore, to design a member so that either (1) the statical breaking load, or (2) the load that causes the most strained fiber of the material to just reach its elastic limit, shall be a number of times the working load. This number is called the *safety factor*. Thus, in the first case, if the statical breaking strength were 12 000 pounds and the working load upon it 2000 pounds, then the safety factor would be 12 000 divided by 2000, or 6. In the second case, if the statical load that causes the most strained fiber of the member to just reach the elastic limit of the material were 6000 pounds and the working load upon it 2000 pounds, then the safety factor on this basis would be 3.

The elastic and ultimate strengths of the materials under static loading can be easily obtained. The strength, therefore, under an assumed steady loading, of any member of a mechanical structure can ordinarily be calculated with sufficient accuracy. But the proper safety factor to use under a given set of actual working conditions, involving actions of a more or less variable or uncertain character, can be arrived at in most cases only as the result of long experience, or by tedious experiment.

Safety Factor for Static Loading. For static loading, which can be estimated with a reasonable degree of exactness, a safety factor of 2, as based upon the elastic limit of the material, will ordinarily be found sufficient. By "static loading" is here meant one that causes a permanent and unvarying straining action.

Safety Factors for Variable Loading. In the absence of more precise data, the following formula, based upon the notable tests on the fatigue of steel under repeated loading, by Wohler and Spangenberg, and the later tests by Bauschinger and at the Watertown Arsenal, may be used in finding the proper safety factor to use for variable loading of an indefinite number of repetitions:

$$F_2 = \left(2 - \frac{P_2}{P_1}\right) F_1. \qquad (1)$$

Or, assuming a safety factor of 2 for static loading, as based upon the elastic limit of the material,

$$F_2 = 4 - \frac{2\,P_2}{P_1}, \qquad (2)$$

where F_1 = safety factor under static loading;

F_2 = corresponding safety factor under a loading that varies repeatedly between the limits P_1 and P_2;

P_1 = greatest pressure due to the variable loading, to be taken as plus (+) if causing tension, and minus (—) if causing compression in the most strained fiber of the member;

P_2 = least pressure due to the variable loading, to be taken as plus (+) if causing tension, and minus (—) if causing compression in the most strained fiber of the member.

This formula is general in its application to an indefinitely great number of repetitions of loading with a known variation of stress. When the loading is of such a character as to cause the stress on the most strained fiber to alternate from tension to compression, care must be taken to give to P_1 and P_2 their proper algebraic signs. When P_2 is zero, or when the variable stress on the most strained fiber is either constantly tension or compression, then the algebraic signs of P_1 and P_2 will be the same and may therefore be ignored.

[24] Book of Standards (National Tube Company) 1913 Edition, pages 268-270.

The following special cases are of frequent occurrence:

1. For a loading that causes an indefinite number of reversals of stress, that is to say, when the alternating tension and compression on the most strained fiber of a member are equal, then $P_2 = -P_1$ and equation (1) becomes

$$F_2 = \left(2 - \frac{-P_1}{P_1}\right) F_1 = (2 + 1)\, F_1 = 3\, F_1. \qquad (3)$$

Or, assuming a safety factor of 2 for static loading, as based upon the elastic limit of the material,

$$F_2 = 6. \qquad (4)$$

This shows for sudden reversals of stress, indefinitely repeated between equal limits of tension and compression, that the safety factor used should be three times that for static loading under otherwise similar conditions.

2. For a loading that causes stresses that alternate indefinitely between zero and a fixed value, $P2 - o$, and equation (1) becomes

$$F_2 = \left(2 - \frac{0}{P_1}\right) F_1 = (2 - 0)\, F_1 = 2\, F_1. \qquad (5)$$

Or, assuming a safety factor of 2 for static loading, as based upon the elastic limit of the material,

$$F_2 = 4. \qquad (6)$$

This shows, for a suddenly applied loading indefinitely repeated, that the safety factor used should be twice that for static loading under otherwise similar conditions.

3. For a steadily applied loading $P2$ will of course equal $P1$, and equation (1) becomes $F_2 = (2 - 1)\, F_1 = F_1$ which shows that formula (1) is correct at its inferior limit.

Safe Working Fiber Stresses. Since for any given material the working fiber stresses for the different conditions of variable loading are inversely proportional to the corresponding safety factors, it is apparent that formula (1) may be put into the following form:

$$f_2 = \frac{f_1}{2 - \frac{P_2}{P_1}}, \qquad (7)$$

where, in addition to the notation as used above, f_1 = working fiber stress under static loading, in pounds per square inch, and f_2 = corresponding working fiber stress under a loading that varies repeatedly between the limits P_1 and P_2.

This formula is general in its application, care being taken to give to P_1 and P_2 their proper algebraic signs, as fully explained in connection with formula (1) above.

The following are important special cases of this formula:

1. For a loading that causes an indefinite number of reversals of stress, the alternating tension and compression on the most strained fiber being equal, $P_2 = -P_1$, and equation (7) becomes

$$f_2 = \frac{f_1}{2 + 1} = \frac{1}{3} f_1. \qquad (8)$$

Or, the safe working fiber stress under this condition is one-third of that under similar static loading.

2. For a loading that causes stresses that alternate indefinitely between zero and a fixed value, whether tension or compression, $P_2 - 0$, and equation (7) becomes

$$f_2 = \frac{f_1}{2 - 0} = \frac{1}{2} f_1. \qquad (9)$$

Or, the safe working fiber stress under this condition is one-half of that under similar static loading.

WATER[25]

Water is composed of two gases, hydrogen and oxygen, in the ratio of two volumes of the former to one of the latter. It is never found pure in nature, owing to the readiness with which it absorbs impurities from the air and soil. Water boils under atmospheric pressure (14.7 pounds at sea level) at 212°, passing off as steam. Its greatest density is at 39.1° Fahr., when it weighs 62.425 pounds per cubic foot.

WEIGHT OF WATER PER CUBIC FOOT AT DIFFERENT TEMPERATURES

Temperature °F.	Weight per cubic foot, pounds	Temperature °F.	Weight per cubic foot, pounds	Temperature °F.	Weight per cubic foot, pounds	Temperature °F.	Weight per cubic foot, pounds	Temperature °F.	Weight per cubic foot, pounds
32	62.42	150	61.18	260	58.55	380	54.36	500	48.7
40	62.42	160	60.98	270	58.26	390	53.94	510	48.1
50	62.41	170	60.77	280	57.96	400	53.5	520	47.6
60	62.37	180	60.55	290	57.65	410	53.0	530	47.0
70	62.31	190	60.32	300	57.33	420	52.6	540	46.3
80	62.23	200	60.12	310	57.00	430	52.2	550	45.6
90	62.13	210	59.88	320	56.66	440	51.7	560	44.9
100	62.02	212	59.83	330	56.30	450	51.2	570	44.1
110	61.89	220	59.63	340	55.94	460	50.7	580	43.3
120	61.74	230	59.37	350	55.57	470	50.2	590	42.6
130	61.56	240	59.11	360	55.18	480	49.7	600	41.8
140	61.37	250	58.83	370	54.78	490	49.2		

VOLUME OF WATER

Cent.	Fahr.	Volume	Cent.	Fahr.	Volume	Cent.	Fahr.	Volume
4°	39.1°	1.00000	35°	95°	1.00586	70°	158°	1.02241
5	41	1.00001	40	104	1.00767	75	167	1.02548
10	50	1.00025	45	113	1.00967	80	176	1.02872
15	59	1.00083	50	122	1.01186	85	185	1.03213
20	68	1.00172	55	131	1.01423	90	194	1.03570
25	77	1.00286	60	140	1.01678	95	203	1.03943
30	86	1.00425	65	149	1.01951	100	212	1.04332

[25] Book of Standards (National Tube Company) 1913 Edition, pages 272-275.

WATER PRESSURE

(From Kent's Mechanical Engineers' Pocket Book)

Comparison of Heads of Water in Feet with Pressures in Various Units

One foot of water at 39.1° F. = 62.425 pounds per square foot;
One foot of water at 39.1° F. = 0.4335 pounds per square inch;
One foot of water at 39.1° F. = 0.0295 atmosphere;
One foot of water at 39.1° F. = 0.8826 inch of mercury at 30°F.;
One foot of water at 39.1° F = 773.3 feet of air at 32° F. and atmospheric pressure;
One pound on the square foot, at 39.1°F. = 0.01602 foot of water;
One pound on the square inch, at 39.1°F. = 2.307 feet of water;
One atmosphere of 29.922 inches of mercury = 33.9 feet of water;
One inch of mercury at 32°F..... = 1.133 feet of water;
One foot of air at 32°F.and 1 atmosphere = 0.001293 foot of water;
One foot of average sea-water..... = 1.026 feet of pure water;
One foot of water at 62°F..... = 62.355 pounds per square foot;
One foot of water at 62°F..... = 0.43302 pounds per square inch;
One inch of water at 62°F. =0.5774 ounce = 0.036085 pound per square in.
One pound of water on the square inch at 62° F..... = 2.3094 feet of water;
One ounce of water on the square inch at 62° F..... = 1.732 inches of water.

Pressure of Water Due to Its Weight. The pressure of still water in pounds per square inch against the sides of any pipe, channel, or vessel of any shape whatever is due solely to the "head" or height of the level surface of the water above the point at which the pressure is considered, and is equal to 0.43302 pound per square inch for every foot of head, or 62.355 pounds per square foot for every foot of head (at 62° F.).

The pressure per square inch is equal in all directions, downwards, upwards, or sideways, and is independent of the shape or size of the containing vessel.

The pressure against a vertical surface, as a retaining-wall, at any point, is in direct ratio to the head above that point, increasing from 0 at the level surface, to a maximum at the bottom. The total pressure against a vertical strip of a unit's breadth increases as the area of a right-angled

triangle whose perpendicular represents the height of the strip and whose base represents the pressure on a unit of surface at the bottom; that is, it increases as the square of the depth. The sum of all the horizontal pressures is represented by the area of the triangle, and the resultant of this sum is equal to this sum exerted at a point one-third of the height from the bottom. (The center of gravity of the area of a triangle is one-third of its height.)

The horizontal pressure is the same if the surface is inclined instead of vertical.

The amount of pressure on the interior walls of a pipe has no appreciable effect upon the amount of flow.

PRESSURE IN POUNDS PER SQUARE INCH FOR DIFFERENT HEADS OF WATER

(At 62° F., 1 foot head = 0.433 pounds per square inch; 0.433 × 144 = 62.352 pounds per cubic foot)

Head, feet	0	1	2	3	4	5	6	7	8	9
0	.....	0.433	0.866	1.299	1.732	2.165	2.598	3.031	3.464	3.897
10	4.330	4.763	5.196	5.629	6.062	6.495	6.928	7.361	7.794	8.227
20	8.660	9.093	9.526	9.959	10.392	10.825	11.258	11.691	12.124	12.557
30	12.990	13.423	13.856	14.289	14.722	15.155	15.588	16.021	16.454	16.887
40	17.320	17.753	18.186	18.619	19.052	19.485	19.918	20.351	20.784	21.217
50	21.650	22.083	22.516	22.949	23.382	23.815	24.248	24.681	25.114	25.547
60	25.980	26.413	26.846	27.279	27.712	28.145	28.578	29.011	29.444	29.877
70	30.310	30.743	31.176	31.609	32.042	32.475	32.908	33.341	33.774	34.207
80	34.650	35.073	35.506	35.939	36.372	36.805	37.238	37.671	38.104	38.537
90	38.970	39.403	39.836	40.269	40.702	41.135	41.568	42.001	42.434	42.867

HEAD IN FEET OF WATER, CORRESPONDING TO PRESSURES IN POUNDS PER SQUARE INCH

(1 pound per square inch = 2.30947 feet head; 1 atmosphere = 14.7 pounds per square inch = 33.94 feet head)

Pressure, lbs.	0	1	2	3	4	5	6	7	8	9
0	.....	2.309	4.619	6.928	9.238	11.547	13.857	16.166	18.476	20.785
10	23.0947	25.404	27.714	30.023	32.333	34.642	36.952	39.261	41.570	43.880
20	46.1894	48.499	50.808	53.118	55.427	57.737	60.046	62.356	64.665	66.975
30	69.2841	71.594	73.903	76.213	78.522	80.831	83.141	85.450	87.760	90.069
40	92.3788	94.688	96.998	99.307	101.62	103.93	106.24	108.55	110.85	113.16
50	115.4735	117.78	120.09	122.40	124.71	127.02	129.33	131.64	133.95	136.26
60	138.5682	140.88	143.19	145.50	147.81	150.12	152.42	154.73	157.04	159.35
70	161.6629	163.97	166.28	168.59	170.90	173.21	175.52	177.83	180.14	182.45
80	184.7576	187.07	189.38	191.69	194.00	196.31	198.61	200.92	203.23	205.54
90	207.8523	210.16	212.47	214.78	217.09	219.40	221.71	224.02	226.33	228.64

Ice and Snow. (From Clark.) 1 cubic foot of ice at 32° F. weighs 57.50 pounds; 1 pound of ice at 32° F. has a volume of 0.0174 cubic foot = 30.067 cubic inches.

Relative volume of ice to water at 32° F., 1.0855, the expansion in passing into the solid state being 8.55 per cent. Specific gravity of ice = 0.922, water at 62° F. being 1.

At high pressures the melting-point of ice is lower than 32° F., being at the rate of 0.0133° F. for each additional atmosphere of pressure.

Specific heat of ice is 0.504, that of water being 1.

1 cubic foot of fresh snow, according to humidity of atmosphere, weighs 5 pounds to 12 pounds. 1 cubic foot of snow moistened and compacted by rain weighs 15 pounds to 50 pounds (Trautwine).

SPECIFIC HEAT OF WATER

(From Marks and Davis's Steam Tables)

Degrees F.	Specific heat	Degrees F.	Specific heat	Degrees F.	Specific heat	Degrees F.	Specific heat	Degrees F.	Specific heat	Degrees F.	Specific heat
20	1.0168	120	0.9974	220	1.007	320	1.035	420	1.072	520	1.123
30	1.0098	130	0.9979	230	1.009	330	1.038	430	1.077	530	1.128
40	1.0045	140	0.9986	240	1.012	340	1.041	440	1.082	540	1.134
50	1.0012	150	0.9994	250	1.015	350	1.045	450	1.086	550	1.140
60	0.9990	160	1.0002	260	1.018	360	1.048	460	1.091	560	1.146
70	0.9977	170	1.0010	270	1.021	370	1.052	470	1.096	570	1.152
80	0.9970	180	1.0019	280	1.023	380	1.056	480	1.101	580	1.158
90	0.9967	190	1.0029	290	1.026	390	1.060	490	1.106	590	1.165
100	0.9967	200	1.0039	300	1.029	400	1.064	500	1.112	600	1.172
110	0.9970	210	1.0050	310	1.032	410	1.068	510	1.117		

Compressibility of Water. Water is very slightly compressible. Its compressibility is from 0.000040 to 0.000051 for one atmosphere, decreasing with increase of temperature. For each foot of pressure, distilled water will be diminished in volume 0.0000015 to 0.0000013. Water is so incompressible that even at a depth of a mile, a cubic foot of water will weigh only about half a pound more than at the surface.

[25] Book of Standards (National Tube Company) 1913 Edition, pages 272-275

FLOW OF WATER IN HOUSE-SERVICE PIPES [26]

(Thomson Meter Company)

Condition of discharge	Pressure in main, pounds per square inch	Discharge in cubic feet per minute — Nominal internal diameter of pipe (inches)							
		½	⅝	¾	1	1½	2	3	4	6
Through 35 feet of service pipe, no back pressure	30	1.10	1.92	3.01	6.13	16.58	33.34	88.16	173.85	444.63
	40	1.27	2.22	3.48	7.08	19.14	38.50	101.80	200.75	513.42
	50	1.42	2.48	3.89	7.92	21.40	43.04	113.82	224.44	574.02
	60	1.56	2.71	4.26	8.67	23.44	47.15	124.68	245.87	628.81
	75	1.74	3.03	4.77	9.70	26.21	52.71	139.39	274.89	703.03
	100	2.01	3.50	5.50	11.20	30.27	60.87	160.96	317.41	811.79
	130	2.29	3.99	6.28	12.77	34.51	69.40	183.52	361.91	925.58
Through 100 feet of service pipe, no back pressure	30	0.66	1.16	1.84	3.78	10.40	21.30	58.19	118.13	317.23
	40	0.77	1.34	2.12	4.36	12.01	24.59	67.19	136.41	366.30
	50	0.86	1.50	2.37	4.88	13.43	27.50	75.13	152.51	409.54
	60	0.94	1.65	2.60	5.34	14.71	30.12	82.30	167.06	448.63
	75	1.05	1.84	2.91	5.97	16.45	33.68	92.01	186.78	501.58
	100	1.22	2.13	3.36	6.90	18.99	38.89	106.24	215.68	579.18
	130	1.39	2.42	3.83	7.86	21.66	44.34	121.14	245.91	660.36
Through 100 feet of service pipe and 15 feet vertical rise	30	0.55	0.96	1.52	3.11	8.57	17.55	47.90	97.17	260.56
	40	0.66	1.15	1.81	3.72	10.24	20.95	57.20	116.01	311.09
	50	0.75	1.31	2.06	4.24	11.67	23.87	65.18	132.20	354.49
	60	0.83	1.45	2.29	4.70	12.94	26.48	72.28	146.61	393.13
	75	0.94	1.64	2.59	5.32	14.64	29.96	81.79	165.90	444.85
	100	1.10	1.92	3.02	6.21	17.10	35.00	95.55	193.82	519.72
	130	1.26	2.20	3.48	7.14	19.66	40.23	109.82	222.75	597.31
Through 100 feet of service pipe and 30 feet vertical rise	30	0.44	0.77	1.22	2.50	6.80	14.11	38.63	78.54	211.54
	40	0.55	0.97	1.53	3.15	8.68	17.79	48.68	98.98	266.59
	50	0.65	1.14	1.79	3.69	10.16	20.82	56.98	115.87	312.08
	60	0.73	1.28	2.02	4.15	11.45	23.47	64.22	130.59	351.73
	75	0.84	1.47	2.32	4.77	13.15	26.95	73.76	149.99	403.98
	100	1.00	1.74	2.75	5.65	15.58	31.93	87.38	177.67	478.55
	130	1.15	2.02	3.19	6.55	18.07	37.02	101.33	206.04	554.96

[26] Book of Standards (National Tube Company) 1913 Edition, page 285.

LOSS OF HEAD IN PIPE BY FRICTION [27]

(Pelton Water Wheel Company)

The following table shows the loss of head by friction in each 100 feet in length of different diameters of pipe, when discharging the tabulated quantities of water per minute:

v = velocity in feet per second; H = loss of head by friction in feet; Q = discharge in cubic feet per minute.

v	Inside diameter of pipe in inches																					
	6		7		8		9		10		11		12		13		14		15		16		18	
	H	Q	H	Q	H	Q	H	Q	H	Q	H	Q	H	Q	H	Q	H	Q	H	Q	H	Q	H	Q
2.0	.39	23.5	.33	32.0	.30	41.9	.26	53.0	.23	65.4	.21	79.	.198	94.	.183	110.	.169	128.	.158	147.	.147	167.	.132	212.
2.2	.46	25.9	.40	35.3	.35	46.1	.31	58.3	.28	72.	.25	87.	.234	103.	.216	121.	.200	141.	.187	162.	.175	184.	.156	233.
2.4	.54	28.2	.46	38.5	.41	50.2	.36	63.6	.32	78.5	.29	95.	.273	113.	.252	133.	.234	154.	.218	176.	.205	201.	.182	254.
2.6	.63	30.6	.54	41.7	.47	54.4	.42	68.9	.37	85.1	.34	103.	.315	122.	.290	144.	.270	167.	.252	191.	.236	218.	.210	275.
2.8	.72	32.9	.61	44.9	.54	58.6	.48	74.2	.43	91.6	.39	111.	.360	132.	.332	156.	.308	179.	.288	206.	.270	234.	.240	297.
3.0	.81	35.3	.69	48.1	.61	62.8	.54	79.5	.48	98.2	.44	119.	.407	141.	.375	166.	.349	192.	.325	221.	.306	251.	.271	318.
3.2	.91	37.7	.78	51.3	.68	67.0	.60	84.8	.54	105.	.49	127.	.457	151.	.422	177.	.392	205.	.366	235.	.343	268.	.305	339.
3.4	1.02	40.0	.87	54.5	.76	71.2	.68	90.1	.61	111.	.55	134.	.510	160.	.471	188.	.438	218.	.408	250.	.383	284	.339	360.
3.6	1.13	42.4	.96	57.7	.84	75.4	.75	95.4	.67	118.	.61	142.	.566	169.	.522	199.	.485	231.	.452	265.	.425	301.	.377	382.
3.8	1.25	44.7	1.07	60.9	.93	79.6	.83	101.	.74	124.	.68	150.	.624	179.	.576	210.	.535	243.	.499	280.	.468	318.	.416	403.
4.0	1.37	47.1	1.17	64.1	1.02	83.7	.91	106.	.82	131.	.74	158.	.685	188.	.632	221.	.587	256.	.548	294.	.513	335.	.456	424.
4.2	1.49	49.5	1.28	67.3	1.12	87.9	.99	111.	.89	137.	.81	166.	.749	198.	.691	232.	.641	269.	.598	309.	.561	352.	.499	445.
4.4	1.62	51.8	1.39	70.5	1.22	92.1	1.08	116.	.97	144.	.88	174.	.815	207.	.751	243.	.698	282.	.651	324.	.611	368.	.542	466.
4.6	1.76	54.1	1.51	73.7	1.32	96.3	1.17	122.	1.05	150.	.96	182.	.883	217.	.815	254.	.757	295.	.707	339.	.662	385.	.588	488.
4.8	1.90	56.5	1.63	76.9	1.43	100.0	1.27	127.	1.14	157.	1.04	190.	.954	226.	.881	265.	.818	308.	.763	353.	.715	402.	.636	509.
5.0	2.05	58.9	1.76	80.2	1.54	105.	1.37	132.	1.23	163.	1.12	198.	1.028	235.	.949	276.	.881	321.	.822	368.	.770	419.	.685	530.
5.2	2.21	61.2	1.89	83.3	1.65	109.	1.47	138.	1.32	170.	1.20	206.	1.104	245.1	1.020	287.	.947	333.	.883	383.	.828	435.	.736	551.
5.4	2.37	63.6	2.03	86.6	1.77	113.	1.57	143.	1.41	177.	1.28	214.	1.183	254.1	1.092	298.	1.014	346.	.947	397.	.888	452.	.788	572.
5.6	2.53	65.9	2.17	89.8	1.89	117.	1.68	148.	1.51	183.	1.37	222.	1.26	264.1	1.167	309.	1.083	359.	1.011	412.	.949	469.	.843	594.
5.8	2.70	68.3	2.31	93.0	2.01	121.	1.80	154.	1.61	190.	1.46	229.	1.34	273.1	1.245	321.	1.155	372.	1.078	427.	1.011	486.	.899	615.
6.0	2.87	70.7	2.46	96.2	2.15	125.	1.92	159.	1.71	196.	1.56	237.	1.43	283.1	1.325	332.	1.229	385.	1.148	442.	1.076	.502	.957	636.
7.0	3.81	82.4	3.26	112.0	2.85	146.	2.52	185.	2.28	229.	2.07	277.	1.91	330.1	.75	387.	1.630	449.	1.520	515.	1.430	.586	1.270	742.

LOSS OF HEAD IN PIPE BY FRICTION (Concluded)

v	Inside diameter of pipe in inches																					
	20		22		24		26		28		30		33		36		39		42		45		48	
	H	Q	H	Q	H	Q	H	Q	H	Q	H	Q	H	Q	H	Q	H	Q	H	Q	H	Q	H	Q
2.0	.119	262.	.108	316.	.098	377.	.091	442.	.084	513.	.079	589.	.073	712.	.066	848.	.061	995.	.057	1155.	.053	1325.	.050	1508.
2.2	.140	288.	.127	348.	.116	414.	.108	486.	.099	564.	.093	648.	.085	785.	.078	933.	.072	1094.	.067	1270.	.063	1456.	.059	1658.
2.4	.164	314.	.149	380.	.136	452.	.126	531.	.116	616.	.109	707.	.100	855.	.091	1018.	.084	1194.	.079	1385.	.073	1590.	.069	1809.
2.6	.189	340.	.171	412.	.157	490.	.145	575.	.134	667.	.126	766.	.115	927.	.104	1100.	.097	1294.	.090	1500.	.084	1721.	.079	1960.
2.8	.216	366.	.195	443.	.180	528.	.165	619.	.153	718.	.144	824.	.131	1000.	.119	1188.	.111	1394.	.103	1617.	.096	1855.	.090	2110.
3.0	.245	393.	.222	475.	.204	565.	.188	663.	.174	770.	.163	883.	.148	1070.	.135	1273.	.125	1492.	.117	1730.	.109	1987.	.102	2260.
3.2	.275	419.	.249	507.	.229	603.	.211	708.	.195	821.	.182	942.	.167	1140.	.152	1367.	.141	1591.	.131	1845.	.122	2120.	.115	2410.
3.4	.306	445.	.278	538.	.255	641.	.235	752.	.218	872.	.204	1001.	.186	1210.	.169	1442.	.157	1690.	.146	1961.	.136	2250.	.128	2560.
3.6	.339	471.	.308	570.	.283	678.	.261	796.	.242	923.	.226	1060.	.206	1282.	.188	1527.	.174	1790.	.162	2079.	.151	2382.	.142	2715.
3.8	.374	497.	.340	601.	.312	716.	.288	840.	.267	973.	.249	1119.	.226	1355.	.207	1612.	.191	1891.	.178	2190.	.166	2515.	.156	2865.
4.0	.410	523.	.373	633.	.342	754.	.315	885.	.293	1026.	.273	1178.	.248	1425.	.228	1697.	.210	1990.	.195	2310.	.182	2650.	.171	3016.
4.2	.449	550.	.408	665.	.374	791.	.345	929.	.320	1077.	.299	1237.	.270	1495.	.249	1782.	.229	2091.	.213	2422.	.198	2780.	.186	3165.
4.4	.488	576.	.444	697.	.407	829.	.375	973.	.348	1129.	.325	1296.	.295	1568.	.271	1866.	.250	2190.	.232	2540.	.216	2910.	.203	3318.
4.6	.529	602.	.482	728.	.441	867.	.407	1017.	.378	1180.	.353	1355.	.321	1640.	.294	1951.	.271	2290.	.252	2658.	.235	3045.	.220	3470.
4.8	.572	628.	.521	760.	.476	905.	.440	1062.	.409	1231.	.381	1414.	.346	1710.	.318	2036.	.293	2389.	.270	2770.	.254	3180.	.238	3619.
5.0	.617	654.	.561	792.	.513	942.	.474	1106.	.440	1283.	.411	1472.	.374	1780.	.342	2121.	.316	2490.	.294	2885.	.273	3310.	.256	3770.
5.2	.662	680.	.602	823.	.552	980.	.510	1150.	.473	1334.	.441	1531.	.403	1852.	.368	2206.	.342	2590.	.317	3000.	.296	3442.	.278	3920.
5.4	.710	707.	.645	855.	.591	1018.	.546	1194.	.507	1385.	.473	1590.	.430	1922.	.394	2291.	.364	2689.	.338	3115.	.315	3578.	.295	4071.
5.6	.758	733.	.690	887.	.632	1055.	.583	1239.	.542	1437.	.506	1649.	.453	1995.	.421	2376.	.393	2790.	.374	3230.	.340	3710.	.319	4222.
5.8	.809	759.	.735	918.	.674	1093.	.622	1283.	.578	1488.	.540	1708.	.495	2065.	.450	2460.	.419	2886.	.389	3348.	.363	3840.	.340	4373.
6.0	.861	785.	.782	950.	.717	1131.	.662	1327.	.615	1539.	.574	1767.	.520	2140.	.479	2545.	.441	2986.	.408	3461.	.382	3970.	.358	4524.
7.0	1.143	916.	1.040	1109.	.953	1319.	.879	1548.	.817	1796.	.762	2061.	.693	2495.	.636	2968.	.586	3484.	.545	4030.	.509	4638.	.476	5277.

The above table is based on Cox's reconstruction of Weisbach's formula, using the denominator 1000 instead of 1200, to be on the safe side, allowing 20% for the loss of head due to the laps and rivet-heads in the pipe.

Example. Given 200 feet head and 600 feet of 11-inch pipe, carrying 119 cubic feet of water per minute. To find the effective head: In right-hand column, under 11-inch pipe, find 119 cubic feet; opposite this will be found the loss by friction in 100 feet of length for this amount of water, which is 0.44. Multiply this by the number of hundred feet of pipe, which is 6, and we have 2.64 feet, which is the loss of head. Therefore the effective head is 200 — 2.64 = 197.36.

Explanation. The loss of head by friction in a pipe depends not only upon diameter and length, but upon the quantity of water passed through it. The head or pressure is what would be indicated by a pressure-gage attached to the pipe near the outlet. Readings of gage should be taken while the water is flowing from the nozzle.

To reduce heads in feet to pressure in pounds multiply by 0.433. To reduce pounds pressure to feet multiply by 2.309.

[27] Book of Standards (National Tube Company) 1913 Edition, pages 286-288.

RELATIVE DISCHARGING CAPACITIES OF PIPE[28]

Actual internal diameter	.269	.364	.493	.622	.824	1.049	1.380	1.610	2.067	2.469	3.068	3.548	4.026	4.506	5.047	6.065
Nominal internal diameter	⅛	¼	⅜	½	¾	1	1¼	1½	2	2½	3	3½	4	4½	5	6
⅛	1															
¼	2.1	1														
⅜	4.5	2.1	1													
½	8	3.8	1.8	1												
¾	16	8	3.6	2	1											
1	30	14	6.6	3.7	1.8	1										
1¼	60	28	13	7	3.6	2	1									
1½	88	41	19	11	5.3	2.9	1.5	1								
2	164	77	36	20	10	5.5	2.7	1.9	1							
2½	255	120	56	31	16	8	4.3	2.9	1.6	1						
3	439	206	97	54	27	15	7	5	2.7	1.7	1					
3½	632	297	139	78	38	21	11	7	3.9	2.5	1.4	1				
4	867	407	191	107	53	29	15	10	5.3	3.4	2	1.4	1			
4½	1 148	539	253	141	70	38	19	13	7	4.5	2.6	1.8	1.3	1		
5	1 525	716	335	188	93	51	26	17	9	6	3.5	2.4	1.8	1.3	1	
6	2 414	1 133	531	297	147	80	40	28	15	9	5.5	3.8	2.8	2.1	1.6	1
7	3 483	1 635	756	428	212	116	58	40	21	14	8	5.5	4	3	2.3	1.4
8	4 795	2 251	1 054	590	292	160	80	55	29	19	10.9	7.6	5.5	4.2	3.1	2
9	6 369	2 990	1 401	783	388	212	107	73	39	25	14	10	7.3	5.5	4.2	2.6
10	8 468	3 976	1 862	1 042	516	282	142	97	52	33	19	13	10	7.4	5.6	3.5
11	10 693	5 020	2 352	1 315	651	356	179	122	65	42	24	17	12	9.3	7	4.4
12	13 292	6 240	2 923	1 635	809	443	223	152	81	52	30	21	15	12	8.7	5.5
13	17 028	7 994	3 745	2 094	1037	567	286	194	104	67	39	27	20	15	11	7
14	20 425	9 589	4 492	2 512	1244	680	343	233	125	80	46	32	24	18	13	8.5
15	24 199	11 361	5 322	2 976	1474	806	406	276	148	95	55	38	28	21	16	10
18 O. D.	31 750	14 906	6 982	3 905	1933	1057	533	362	194	124	72	50	37	28	21	13
20 O. D.	41 928	19 685	9 221	5 157	2553	1396	703	478	256	164	95	66	48	37	27	17
22 O. D.	53 848	25 281	11 842	6 623	3279	1793	903	614	329	211	123	85	62	47	35	22
24 O. D.	67 599	31 737	14 866	8 315	4116	2251	1134	771	413	265	154	107	78	59	44	28
26 O. D.	83 267	39 093	18 312	10 242	5070	2773	1397	950	509	326	190	132	96	73	55	34
28 O. D.	100 932	47 387	22 197	12 415	6146	3361	1693	1152	617	395	230	160	116	88	66	42
30 O. D.	120 675	56 655	26 539	14 843	7348	4018	2024	1377	737	473	275	191	139	105	79	50

Calculations based on the inside diameters of standard pipe, page 56.

Formula

Relative discharge capacity = $\sqrt{\text{inside diameter}^5}$.

RELATIVE DISCHARGING CAPACITIES OF PIPE (Concluded)

Actual internal diameter	7.023	7.981	8.941	10.020	11.000	12.000	13.250	14.250	15.250	17.000	19.000	21.000	23.000	25.000	27.000	29.000
Nominal internal diameter	7	8	9	10	11	12	14 O. D.	15 O. D.	16 O. D.	18 O. D.	20 O. D.	22 O. D.	24 O. D.	26 O. D.	28 O. D.	30 O. D.
⅛																
¼																
⅜																
½																
¾																
1																
1¼																
1½																
2																
2½																
3																
3½																
4																
4½																
5																
6																
7	1															
8	1.3	1														
9	1.8	1.3	1													
10	2.4	1.8	1.3	1												
11	3	2.2	1.7	1.3	1											
12	3.8	2.8	2.1	1.6	1.2	1										
13	4.9	3.6	2.7	2	1.6	1.3	1									
14	5.9	4.3	3.2	2.4	1.9	1.5	1.2	1								
15	6.9	5	3.8	2.9	2.3	1.8	1.4	1.2	1							
18 O. D.	9.1	6.6	5	3.7	3	2.4	1.9	1.6	1.3	1						
20 O. D.	12	8.7	6.6	5	3.9	3.2	2.5	2.1	1.7	1.3	1					
22 O. D.	15	11	8.5	6.4	5	4.1	3.2	2.6	2.2	1.7	1.3	1				
24 O. D.	19	14	11	8	6.3	5.1	4	3.3	2.8	2.1	1.6	1.3	1			
26 O. D.	24	17	13	9.8	7.8	6.3	4.9	4.1	3.4	2.6	2	1.5	1.2	1		
28 O. D.	29	21	16	12	9.4	7.6	5.9	4.9	4.2	3.2	2.4	1.9	1.5	1.2	1	
30 O. D.	35	25	19	14	11	9.1	7.1	5.9	5	3.8	2.9	2.2	1.8	1.4	1.2	1

Calculations based on the inside diameters of standard pipe, page 56.

Formula

Relative discharge capacity = $\sqrt{\text{inside diameter}^5}$.

[28] Book of Standards (National Tube Company) 1913 Edition, pages 306-309.

FLOW OF STEAM[29]

Flow of Steam from Orifices. The flow of steam of a higher pressure toward a lower pressure increases as the difference of pressure is increased, until the external pressure becomes only 58 per cent of the absolute initial pressure. Any further reduction of the external pressure, even to the extent of a perfect vacuum, neither increases nor diminishes the flow of steam. In flowing through a nozzle of the best form, the steam expands to the external pressure and to the volume corresponding to this pressure, so long as it is not less than 58 per cent of the internal pressure. For an external pressure of 58 per cent or less, the ratio of expansion is 1.624.

The following formula is frequently used to determine the flow of steam through an orifice against a pressure greater than 58 per cent of the discharge:

$$W = 1.9\,AK\,\sqrt{(P - d)\,d},$$

where

W = weight discharged in pounds per minute;
A = area of orifice in square inches;
P = absolute initial pressure in pounds per square inch;
d = difference in pressure between the two sides, in pounds per square inch;
K = coefficient = .93 for a short pipe = .63 for a hole in a thin plate.

Flow of Steam into the Atmosphere. When steam of varying initial pressure is discharged into the atmosphere—the atmospheric pressure being not more than 58 per cent of the initial pressure — the velocity of outflow at constant density, that is, supposing the initial density to be maintained, is given by the formula,

$$V = 3.5953\,\sqrt{h},$$

where V = the velocity of outflow in feet per second, as for steam of the initial density, and h = the height in feet, of a column of steam of the given initial pressure, the weight of which is equal to the pressure on the unit of base.

The lowest initial pressure to which this formula applies, when steam is discharged into the atmosphere, is 25.37 pounds per square inch.

The following table gives the outflow of steam into the atmosphere for various internal pressures. The velocity of steam above 25.37 pounds per square inch absolute pressure, increases very slowly with the pressure, because the density, and the weight to be moved, increase with the pressure. An average of 900 feet per second may, for approximate calculations, be taken for the velocity of outflow as for constant density, that is, taking the volume of the steam at the initial volume.

OUTFLOW OF STEAM INTO THE ATMOSPHERE
(D. K. Clark)

Initial pressure, pounds per square inch absolute	External pressure, pounds per square inch absolute	Expansion in nozzle, ratio	Velocity of outflow at constant density, feet per second	Actual velocity of outflow expanded, feet per second	Discharge, pounds per square inch per minute
25.37	14.7	1.624	863	1401	22.81
30	14.7	1.624	867	1408	26.84
40	14.7	1.624	874	1419	35.18
45	14.7	1.624	877	1424	39.78
50	14.7	1.624	880	1429	44.06
60	14.7	1.624	885	1437	52.59
70	14.7	1.624	889	1444	61.07
75	14.7	1.624	891	1447	65.30
90	14.7	1.624	895	1454	77.94
100	14.7	1.624	898	1459	86.34
115	14.7	1.624	902	1466	98.76
135	14.7	1.624	906	1472	115.61
155	14.7	1.624	910	1478	132.21
165	14.7	1.624	912	1481	140.46
215	14.7	1.624	919	1493	181.58

Napier's approximate formula for the outflow of steam into the atmosphere, when the pressure of the atmosphere receiving the steam is less than 58 per cent of the initial pressure, is $W = ap \div 70$, where W is weight discharged, in pounds per second, a = area of orifice in square inches, and p = absolute initial pressure in pounds per square inch.

Flow of Steam in Pipes. The most generally accepted formula for the flow of steam in pipes is

$$W = 87\,\sqrt{\frac{w(p_1 - p_2)\,d^5}{L\left(1+\frac{3.6}{d}\right)}} \qquad (1)$$

or

$$p_1 - p_2 = 0.000132\left(1+\frac{3.6}{d}\right)\frac{W^2 L}{w d^5} \qquad (2)$$

where W = weight of steam in pounds per minute;
p_1 = initial pressure in pounds per square inch;
p_2 = final pressure in pounds per square inch;
L = length of pipe in feet;
d = inside diameter of pipe in inches;
w = density of steam in pounds per cubic foot.

The quantity of steam flowing with a given drop in pressure may be calculated by formula (1), while the drop for a given flow may be obtained from formula (2). The following table computed by E. C. Sickles (Trans. A. S. M. E., XX, 354) is calculated by a formula which, when reduced to a form similar to that of formula (1), gives a coefficient 87.45 instead of 87.

Table I gives the discharge in pounds per minute for pipes of various diameters corresponding to drops of pressure as given in Table II. The drops of pressure are computed for a length of 1000 feet; for any other length the drop is proportional to the length divided by 1000. In using the table the absolute pressure should be taken as the mean of the initial and final pressures in computing the carrying capacity.

TABLE I.—STEAM IN POUNDS PER MINUTE, CORRESPONDING TO DROP IN PRESSURE IN TABLE II

Diameter	24	22	20	18	16	15	14	13	12	11	10
Line											
1	14 000	11 188	8772	6678	4923	4163	3481	2871	2328	1853	1443
2	13 000	10 392	8144	6203	4573	3867	3233	2667	2165	1721	1341
3	12 000	9 593	7517	5724	4220	3569	2983	2461	1996	1589	1237
4	11 000	8 804	6891	5247	3868	3271	2736	2256	1830	1456	1134
5	10 000	7 992	6265	4770	3517	2974	2486	2051	1663	1324	1031
6	9 500	7 705	5947	4532	3341	2825	2362	1940	1580	1258	979
7	9 000	7 205	5638	4293	3165	2676	2237	1846	1497	1192	928
8	8 500	6 905	5321	4054	2989	2527	2113	1743	1414	1125	876
9	8 000	6 506	5012	3816	2814	2379	1989	1640	1331	1059	825
10	7 500	6 106	4695	3577	2638	2230	1865	1538	1248	993	773
11	7 000	5 707	4385	3339	2462	2082	1740	1435	1164	927	722
12	6 500	5 307	4069	3100	2286	1933	1616	1333	1081	860	670
13	6 000	4 908	3758	2862	2110	1784	1492	1230	998	794	619
14	5 500	4 508	3443	2623	1934	1635	1368	1128	915	728	567
15	5 000	4 108	3132	2385	1758	1487	1243	1025	832	662	516

Diameter	9	8	7	6	5	4	3½	3	2½	2	1½	1
Line												
1	1093	799	560	371	227	123	71.6	55.9	28.8	18.1	6.81	2.52
2	1015	742	521	344	210	114.6	68.6	51.9	27.6	16.8	6.52	2.34
3	937	685	481	318	194	106.0	65.6	47.9	26.4	15.5	6.24	2.16
4	859	628	441	292	178	97.0	62.7	43.9	25.2	14.2	5.95	1.98
5	781	571	401	265	162	88.2	59.7	39.9	24.0	12.9	5.67	1.80
6	742	542	381	252	154	83.8	56.5	37.9	22.8	12.3	5.29	1.17
7	703	514	361	239	146	79.4	53.5	35.9	21.6	11.6	5.00	1.62
8	664	485	341	226	138	75.0	50.5	33.9	20.4	10.9	4.72	1.53
9	625	457	321	212	130	70.6	47.6	31.9	19.2	10.3	4.43	1.44
10	586	428	301	199	122	66.2	44.5	29.9	18.0	9.68	4.15	1.35
11	547	400	281	186	113	61.7	41.6	27.9	16.8	9.03	3.86	1.26
12	508	371	261	172	105	57.3	38.6	25.9	15.6	8.38	3.68	1.17
13	469	343	241	159	97.2	52.9	35.6	23.9	14.4	7.74	3.40	1.08
14	430	314	221	146	89.1	48.5	32.6	21.9	13.2	7.10	3.11	0.99
15	390	286	200	132	81.0	44.1	29.6	20.0	12.0	6.45	2.83	0.90

[29] Book of Standards (National Tube Company) 1913 Edition, pages 341-346.

TABLE II.—DROP IN PRESSURE IN POUNDS PER SQUARE INCH PER 1000 FEET LENGTH, CORRESPONDING TO DISCHARGE IN TABLE I

Density	0.208	0.230	0.273	0.295	0.316	0.338	0.401	0.443	0.485	0.548
Pressure	90	100	120	130	140	150	180	200	220	250
Line										
1	18.1	16.4	13.8	12.8	11.9	11.1	9.39	8.50	7.76	6.87
2	15.6	14.1	11.9	11.0	10.3	9.60	8.09	7.33	6.69	5.92
3	13.3	12.0	10.1	9.38	8.75	8.18	6.90	6.24	5.70	5.05
4	11.1	10.0	8.46	7.83	7.31	6.83	5.76	5.21	4.76	4.21
5	9.25	8.36	7.5	6.52	6.09	5.69	4.80	4.34	3.97	3.51
6	8.33	7.53	6.35	5.87	5.48	5.13	4.32	3.91	3.57	3.16
7	7.48	6.76	5.70	5.27	4.92	4.60	3.88	3.51	3.21	2.84
8	6.67	6.03	5.08	4.70	4.39	4.10	3.46	3.13	2.86	2.53
9	5.91	5.35	4.50	4.17	3.89	3.64	3.07	2.78	2.53	2.24
10	5.19	4.69	3.95	3.66	3.42	3.19	2.69	2.44	2.23	1.97
11	4.52	4.09	3.44	3.19	2.98	2.78	2.34	2.12	1.94	1.72
12	3.90	3.53	2.97	2.75	2.57	2.40	2.02	1.83	1.67	1.48
13	3.32	3.00	2.53	2.34	2.19	2.04	1.72	1.56	1.42	1.26
14	2.79	2.52	2.13	1.97	1.84	1.72	1.45	1.31	1.20	1.06
15	2.31	2.09	1.76	1.63	1.52	1.42	1.20	1.08	0.991	0.877

Density in pounds per cubic foot. Pressure in pounds per square inch absolute.

Examples in the Use of the Table. Suppose it is required to find the discharge from a 5-inch pipe line, steam pressure being 120 pounds per square inch absolute, and the loss in pressure being 4.5 pounds per 1000 feet length. In Table II we find the drop 4.5 under 120 pounds pressure to be in line 9. In Table I in line 9 under 5-inch diameter we find the discharge to be 130 pounds per minute.

Or, suppose it is required to find the size of pipe to carry 1000 pounds of steam per minute, mean absolute pressure being 130 pounds and the drop in pressure being assumed as 11 pounds. In Table II the drop 11 under 130 pounds pressure is in line 2. In Table I in line 2 the tabular quantity which corresponds nearest to 1000 is in the 9-inch column. A 9-inch line will, therefore, be required.

Kent modifies Darcy's formula for flow of water to make it apply to steam, and gives for the flow,

$$Q = c\sqrt{\frac{(p_1 - p_2)d^5}{wL}},$$

$$W = c\sqrt{\frac{w(p_1 - p_2)d^5}{L}},$$

where Q = volume of steam in cubic feet per minute;
W = weight of steam in pounds per minute;
p_1 = initial pressure in pounds per square inch;
p_2 = final pressure in pounds per square inch;
L = length of pipe in feet;
d = inside diameter of pipe in inches;
w = density of steam in pounds per cubic foot;
c = coefficient, depending on the diameter of the pipe.

The values of c are as follows:

Nominal diameter, inches	½	¾	1	1¼	1½	2	2½	3
Value of c	36.8	42	45.3	48	50	52.7	54.8	56.2
Nominal diameter, inches	3½	4	4½	5	6	7	8	9
Value of c	57.1	57.8	58.3	58.7	59.5	60.2	60.8	61.3
Nominal diameter, inches	10	12	14	16	18	20	22	24
Value of c	61.7	62.1	62.3	62.6	62.7	62.9	63.2	63.2

Flow of Steam in Low-pressure Heating Lines. The following table by W. Kent (A. S. H. V. E., 1907) is based on his adaptation of Darcy's formula for flow of water to the flow of steam as given above. The drop in pressure assumed is 1 pound per 1000 feet, as a basis from which the flow at any drop may be calculated.

FLOW OF STEAM AT LOW PRESSURE IN POUNDS PER HOUR FOR A UNIFORM DROP AT THE RATE OF 1 POUND PER 1000 FEET LENGTH OF STRAIGHT PIPE

Nominal diameter of pipe	Initial steam pressure, pounds (gage)								
	0.3	1.3	2.3	3.3	4.3	5.3	6.3	8.3	10.3
	Flow of steam, pounds per hour								
Ins.									
½	4.2	4.3	4.4	4.6	4.7	4.8	4.9	5.1	5.3
¾	9.7	10.0	10.3	10.5	10.8	11.0	11.3	11.8	12.3
1	19.0	19.6	20.2	20.7	21.2	21.7	22.3	23.2	24.2
1¼	40.1	41.3	42.5	43.7	44.8	45.9	46.9	49.0	50.9
1½	61.4	63.2	65.1	66.8	68.6	70.3	71.9	75.0	78.0
2	120.8	124.5	128.2	131.6	135.0	138.3	141.5	147.7	153.6
2½	195.7	201.8	207.5	213.2	218.7	224.0	229.2	239.2	248.8
3	345.5	356.1	366.5	376.4	386.1	395.5	404.7	422.4	439.3
3½	505.3	520.8	535.9	550.5	564.7	578.5	591.8	618.0	642.6
4	701.4	723.0	744.0	764.4	784.2	803.4	822.	857.4	891.6
4½	938.7	967.6	995.8	1023.	1049.	1075.	1100.	1148.	1193.
5	1252.	1291.	1328.	1364.	1399.	1433.	1467.	1531.	1592.
6	2011.	2074.	2134.	2192.	2248.	2303.	2356.	2459.	2557.
7	2936.	3027.	3115.	3199.	3281.	3362.	3440.	3590.	3733.
8	4082.	4208.	4331.	4448.	4564.	4674.	4783.	4991.	5191.
9	5462.	5630.	5794.	5951.	6102.	6252.	6396.	6678.	6942.
10	7314.	7536.	7758.	7968.	8172.	8370.	8562.	8940.	9294.
12	11550.	11916.	12264.	12594.	12918.	13236.	13542.	14136.	14700.

For any other drop of pressure per 1000 feet length, multiply the figures in the table by the square root of that drop.

Kent says, "In all cases the judgment of the engineer must be used in the assumption of the drop to be allowed. For small distributing pipes it will generally be desirable to assume a drop of not more than one pound per 1000 feet to insure that each single radiator shall always have an ample supply for the worst conditions, and in that case the size of piping given in the table up to two inches may be used; but for main pipes supplying totals of more than 500 square feet, greater drops may be allowed."

Resistance Due to Entrance, Bends and Valves. Mr. Briggs states, in "Warming Buildings by Steam," that the resistance at the entrance to a pipe consists of two parts, namely, the head $\frac{v^2}{2g}$ which is necessary to create the velocity of flow, and the head 0.505 $\frac{v^2}{2g}$, which overcomes the resistance to entrance offered by the mouth of the pipe. The total loss of head at entrance then equals the sum of these, or 1.505 $\frac{v^2}{2g}$, in which v = velocity of flow of steam in the pipe, in feet per second, and g = acceleration due to gravity, or 32.2.

The Babcock & Wilcox Co. state in "Steam" that the resistance at the opening, and that at a globe valve, are each about the same as that caused by an additional length of straight pipe, as computed by the formula,

$$L = \frac{114D}{1 + (3.6 \div D)},$$

where L is the additional length of pipe in inches and D is the diameter of pipe in inches. From this formula has been computed the following table:

D in inches	1	1½	2	2½	3	3½	4	5	6
L in feet	2	4	7	10	13	16	20	28	36
D in inches	7	8	10	12	15	18	20	22	24
L in feet	44	53	70	88	115	143	162	181	200

The resistance to flow at a right-angled elbow is about equal to two-thirds that of a globe valve.

The above values are to be considered as being only approximations to the truth.

Expansion of Steam Pipes [30]. The linear expansion and contraction of a pipe carrying steam, with the rise and fall of the temperature, must be taken care of by the use of some form of expansion joint or bend. To find the total expansion due to an increase in temperature, multiply the length of pipe in inches by the coefficient of expansion and by the temperature range.

The expansion for each 100 feet of length for different degrees Fahrenheit is given in the following table, which is taken from the Practical Engineer, January, 1911. The expansion for any length between two temperatures is found by taking the difference in length at these temperatures, dividing by 100 and multiplying by the length of the pipe in feet.

EXPANSION OF PIPES

(Increase in inches per 100 feet)

Temperature, degrees Fahrenheit	Cast Iron	Wrought Iron	Steel	Brass and Copper
0	0.00	0.00	0.00	0.00
50	0.36	0.40	0.38	0.57
100	0.72	0.79	0.76	1.14
125	0.88	0.97	0.92	1.40
150	1.10	1.21	1.15	1.75
175	1.28	1.41	1.34	2.04
200	1.50	1.65	1.57	2.38
225	1.70	1.87	1.78	2.70
250	1.90	2.09	1.99	3.02
275	2.15	2.36	2.26	3.42
300	2.35	2.58	2.47	3.74
325	2.60	2.86	2.73	4.13
350	2.80	3.08	2.94	4.45
375	3.15	3.46	3.31	5.01
400	3.30	3.63	3.46	5.24
425	3.68	4.05	3.86	5.85
450	3.89	4.28	4.08	6.18
475	4.20	4.62	4.41	6.68
500	4.45	4.90	4.67	7.06
525	4.75	5.22	4.99	7.55
550	5.05	5.55	5.30	8.03
575	5.36	5.90	5.63	8.52
600	5.70	6.26	5.98	9.06
625	6.05	6.65	6.35	9.62
650	6.40	7.05	6.71	10.18
675	6.78	7.46	7.12	10.78
700	7.15	7.86	7.50	11.37
725	7.58	8.33	7.96	12.06
750	7.96	8.75	8.36	12.66
775	8.42	9.26	8.84	13.38
800	8.87	9.76	9.31	14.10

Sizes of Steam Pipes for Engines. A common rule is that steam pipes supplying stationary engines should be of such size that the mean velocity of steam in them does not exceed 6000 feet per minute, in order that the loss due to friction may not be excessive. There are many cases where this rule gives unnecessarily large pipes, and the velocity could be increased with advantage. The larger the pipe, the greater the surface, and the greater the amount of condensation. For large engines and high pressures it is best to assume the drop in pressure and calculate the diameter from the formulae given above, or obtain it from the tables. In marine work the steam pipes are generally not as large as in stationary practice for the same size of cylinders, a velocity of 9000 feet per minute being often used. In proportioning exhaust pipes the velocity should not exceed 4000 feet per minute for stationary engines, nor 6000 feet for marine engines.

Having assumed a velocity of flow in the pipe supplying steam to the engine, the size of pipe required is such that its area is given by the formula

$$\text{Pipe Area} = \frac{\text{Cylinder Area} \times \text{Piston Speed}}{\text{Mean Velocity of Steam in Pipe}}.$$

Or, since the areas are proportional to the squares of their diameters,

$$\text{Pipe Diameter} = \sqrt{\frac{(\text{Cylinder Diameter})^2 \times \text{Piston Speed}}{\text{Mean Velocity of Steam in Pipe}}}.$$

This assumes that steam is admitted during full stroke.

[30] Book of Standards (National Tube Company) 1913 Edition, pages 346-347.

Length of Pipe for One Square Foot of Surface [31]

Size	External diameter	Standard weight pipe: Thickness	Standard weight pipe: Length of pipe in ft. per sq. ft. of external surface	Standard weight pipe: Length of pipe in ft. per sq. ft. of internal surface	Extra strong pipe: Thickness	Extra strong pipe: Length of pipe in ft. per sq. ft. of external surface	Extra strong pipe: Length of pipe in ft. per sq. ft. of internal surface	Double extra strong pipe: Thickness	Double extra strong pipe: Length of pipe in ft. per sq. ft. of external surface	Double extra strong pipe: Length of pipe in ft. per sq. ft. of internal surface
1/8	.405	.068	9.431	14.199	.095	9.431	17.766	.....	.....	.....
1/4	.540	.088	7.073	10.493	.119	7.073	12.648	.....	.....	.....
3/8	.675	.091	5.658	7.747	.126	5.658	9.030	.....	.....	.....
1/2	.840	.109	4.547	6.141	.147	4.547	6.995	.294	4.547	15.157
3/4	1.050	.113	3.637	4.635	.154	3.637	5.147	.308	3.637	8.801
1	1.315	.133	2.904	3.641	.179	2.904	3.991	.358	2.904	6.376
1 1/4	1.660	.140	2.301	2.767	.191	2.301	2.988	.382	2.301	4.263
1 1/2	1.900	.145	2.010	2.372	.200	2.010	2.546	.400	2.010	3.472
2	2.375	.154	1.608	1.847	.218	1.608	1.969	.436	1.608	2.541
2 1/2	2.875	.203	1.328	1.547	.276	1.328	1.644	.552	1.328	2.156
3	3.500	.216	1.091	1.245	.300	1.091	1.317	.600	1.091	1.660
3 1/2	4.000	.226	.954	1.076	.318	.954	1.135	.636	.954	1.400
4	4.500	.237	.848	.948	.337	.848	.998	.674	.848	1.211
4 1/2	5.000	.247	.763	.847	.355	.763	.890	.710	.763	1.066
5	5.563	.258	.686	.756	.375	.686	.793	.750	.686	.940
6	6.625	.280	.576	.629	.432	.576	.663	.864	.576	.780
7	7.625	.301	.500	.543	.500	.500	.576	.875	.500	.650
8	8.625	.277	.442	.473	.500	.442	.500	.875	.442	.555
8	8.625	.322	.442	.478	.....	.....	.....	.....	.....	.....
9	9.625	.342	.396	.427	.500	.396	.442	.....	.....	.....
10	10.750	.279	.355	.374	.500	.355	.391	.....	.....	.....
10	10.750	.307	.355	.376	.....	.....	.....	.....	.....	.....
10	10.750	.365	.355	.381	.....	.....	.....	.....	.....	.....
11	11.750	.375	.325	.347	.500	.325	.355	.....	.....	.....
12	12.750	.330	.299	.315	.500	.299	.325	.....	.....	.....
12	12.750	.375	.299	.318	.....	.....	.....	.....	.....	.....
13	14.000	.375	.272	.288	.500	.272	.293	.....	.....	.....
14	15.000	.375	.254	.268	.500	.254	.272	.....	.....	.....
15	16.000	.375	.238	.250	.500	.238	.254	.....	.....	.....

LOSS OF HEAT FROM STEAM PIPES [32]

Loss of Heat from Bare Steam Pipes. A bare pipe carrying steam and made of steel, iron or other conducting material, loses heat by convection to the surrounding air and by radiation to the surrounding objects, both of which cause a loss of steam by condensation.

For bare steam pipes this loss may be taken as 2.7 B. T. U. per hour per square foot of surface per degree Fahr. difference between the temperatures of the steam and the outside air. Thus, if the pressure of the steam is 120 pounds absolute, the corresponding temperature being 341 degrees, and the temperature of the air 60 degrees, then the loss per hour per foot length from a 4-inch steam pipe, the external surface of which is 1.178 square feet per foot of length, will be $1.178 \times (341 - 60) \times 2.7 = 894$ B. T. U.

Condensation in Bare Steam Pipes. The corresponding condensation can be found by dividing this heat quantity by the latent heat of steam at the given pressure. In the example given above, the latent heat of steam at 120 pounds pressure, absolute, is 877.2 B. T. U. Therefore the condensation per hour per foot length of pipe is $894 \div 877.2 = 1.02$ pounds.

Steam Pipe Coverings. This loss is lessened in practice by covering the steam pipe with a material that will offer a greater resistance to the flow of heat than that offered by the material of the pipe. A good material for this purpose should not suffer serious deterioration from the heat or vibration to which it would be subjected in practice; and in all cases where damage from fire might result, it should never consist of combustible matter. Any covering should be kept perfectly dry, as still water is an excellent carrier of heat.

The best insulating substance known is air confined in minute cells, and the best nonconducting coverings owe their efficiency to the numerous air

[31] Book of Standards (National Tube Company) 1913 Edition, page 57.

[32] Book of Standards (National Tube Company) 1913 Edition, pages 348-350.

cells in their structure. In general the value of a covering is inversely proportional to its weight, and other things being equal, the incombustible mineral substances are to be preferred to combustible material. No covering should be less than one inch in thickness.

Hair or wool felt and most of the better nonconducting materials have the disadvantage of becoming charred at high temperature and partly losing their insulating power. There is also the danger of taking fire. Mineral wool, a fibrous material made from blast furnace slag, is the best noncombustible covering, but being brittle it is liable to fall to a powder when subjected to jarring.

Pipe covering may be sectional, or plastic. The former is built up in sections and attached to the pipe by bands, which allow easy removal of the covering. The latter is put on in a soft, plastic condition, and is hardened in place; it obviates joints and adheres closely to the pipe.

The following table, taken from the various sources noted, gives the results of experiments on steam pipe coverings. In almost all cases the figures given are the averages of a number of tests.

STEAM PIPE COVERINGS

Number	Kind of Covering	Size of pipe, ins.	Thickness of covering, inches	B. T. U. per square foot per hour per degree difference of temperature	Per cent heat lost	Authority
1	Bare pipe	.....	.....	2.7	100	
2	Mineral wool	8	1.30	0.285	10.6	Brill
3	Rock wool	8	1.60	0.256	9.5	Brill
4	Hair felt	2	0.96	0.387	14.3	Jacobus
5	Hair felt	8	0.82	0.422	15.6	Brill
6	Remanit	2	1.51	0.302	11.2	Stott
7	Remanit	2	1.30	0.363	13.4	Jacobus
8	Remanit	2	0.88	0.434	16.1	Jacobus
9	Solid cork	2	1.68	0.348	12.9	Stott
10	Solid cork	2	1.20	0.427	15.8	Stott
11	Magnesia	2	2.41	0.302	11.2	Stott
12	Magnesia	10	1.37	0.354	13.1	Barrus
13	Magnesia	8	1.25	0.384	14.2	Brill
14	Magnesia	2	1.16	0.439	16.3	Stott
15	Magnesia	4	1.12	0.465	17.2	Norton
16	Magnesia	2	1.08	0.304	11.3	Jacobus
17	Magnesia	2	1.08	0.531	19.7	Barrus
18	Asbestos sponge felted	2	1.14	0.260	9.6	Jacobus
19	Asbestos sponge felted	10	1.63	0.280	10.4	Barrus
20	Asbestos sponge felted	2	1.21	0.490	18.1	Barrus
21	Asbestos sponge felted	2	1.24	0.532	19.7	Stott
22	Manville sectional	8	1.70	0.350	13.0	Brill
23	Manville sectional	4	1.25	0.453	16.8	Norton
24	Manville sectional	2	1.31	0.572	21.2	Paulding
25	Asbestos air cell	2	1.26	0.486	18.0	Stott
26	Asbestos air cell	4	1.12	0.525	19.4	Norton
27	Asbestos air cell	2	0.96	0.716	26.5	Jacobus
28	Asbestos air cell	2	1.02	0.793	29.4	Barrus
29	Asbestos fire felt	8	1.30	0.502	18.6	Brill
30	Asbestos fire felt	2	1.00	0.721	26.7	Paulding
31	Asbestos fire felt	2	0.99	0.766	28.4	Jacobus
32	Fossil meal	8	0.75	0.879	32.6	Brill
33	Riley cement	8	0.75	0.953	35.3	Brill

A brief description of some of these coverings is given below:

No. 4. A layer of asbestos paper $\frac{1}{32}$ inch thick next to the pipe, then the hair felt, then a layer of paper, and outside of all a canvas covering.

No. 5. The hair felt was bound tightly around the pipe, with no canvas covering; it had a layer of asbestos paper under it.

No. 6. A covering composed of two layers wound in reverse direction with ropes of carbonized silk; the inner layer 2½ inches wide and ½ inch thick; the outer layer 2 inches wide and ¾ inch thick, over which was wound a network of wire; ⅛ inch asbestos next to pipe.

No. 7. A grade known as high-pressure remanit; encased in canvas.

No. 8. A grade known as intermediate-pressure remanit; encased in canvas.

Nos. 9 and 10. Solid sectional covering of granulated cork with ⅛ inch asbestos paper next to pipe.

No. 11. 85 per cent carbonate of magnesia. Average of a number of tests of moulded sectionals, thickness of covering ranging from 2.20 to 2.71 inches.

No. 12. Carbonate of magnesia with some asbestos fiber; outside finished with canvas.

No. 14. Average of tests, thickness of covering ranging from 1.12 to 1.19 inches.

No. 15. Moulded sectional covering composed of about 90 per cent carbonate of magnesia.

No. 17. Similar, except in thickness, to No. 12.

Nos. 18, 19, 20 and 21. Laminated sectional, composed of a number of layers of asbestos paper in which were imbedded small pieces of sponge.

No. 23. A sectional covering composed of an inner layer of earthy material covered by a layer of wool felt.

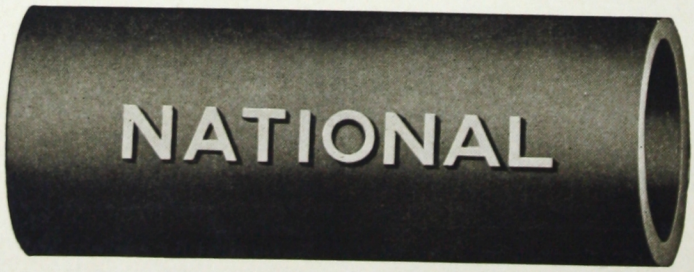
No. 25. Laminated sectional with ⅛ inch asbestos paper next to pipe.

No. 26. Made of thin sheets of corrugated asbestos paper, stuck together with silicate of soda.

Nos. 27 and 28. Similar to No. 26.

Nos. 32 and 33. Mixed with water and plastered on the pipe.

MARKING



Name Rolled in Raised Letters on National Tube Company Pipe

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"NATIONAL" BULLETINS

The tubular industry covers a field so broad that it is scarcely practicable to place between two covers all the ramifications. In order to meet a growing demand for detailed information, National Tube Company began some time since to collect, through their Research Department, Salesmen, Customers and similar sources, tubular data, and then to arrange and publish same in the form of "NATIONAL" BULLETINS.

No expense has been spared in the original research work, in the literary preparation of the accumulated material, in the making of the numerous illustrations and in the final printing and publication. It needs no further explanation to indicate that "NATIONAL" Bulletins are *not* provided for a broadcast distribution as merely advertising. These Bulletins are practically technical text books on distinct applications of tubular material and allied products.

"NATIONAL" Bulletins are furnished free of all charge to those whose letterhead or business activities would indicate a legitimate use. While in some special cases a complete file for reference may be desirable, yet for the most part we believe only those Bulletins which treat of certain allied subjects will be necessary.

For example: One who is interested in "NATIONAL" Bedstead Tubing would scarcely be interested in "NATIONAL" Pipe for Refrigerating Systems, or in those Bulletins devoted to the subject of Corrosion.

The summary of contents of "NATIONAL" Bulletins following will be found sufficiently comprehensive that one can decide without difficulty which Bulletin or Bulletins is required for his purpose, and has only to ask for such as required by name and number from the nearest District Sales Office to receive his choice free of all charge.

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"NATIONAL" BULLETIN No. 1—SOME RECENT DEVELOPMENTS IN TESTING BOILER TUBES (eight pages, seven illustrations). This Bulletin contains a paper prepared by F. N. Speller, Metallurgical Engineer, National Tube Company, and presented at 14th Annual Meeting American Society for Testing Materials, Atlantic City, N. J., June 27th to July 1st, 1911. The test applied to each Spellerized Steel Locomotive Boiler Tube is described in full. Briefly this test is made on the two crop ends from each tube, whereby a special manipulation test is given, containing in one piece the vertical crushing, horizontal flattening, expanding and flanging tests. This Bulletin also contains Standard Specifications for Lap-Weld and Seamless Steel Boiler Tubes, Safe Ends and Arch Tubes (including Super-heater Tubes), as jointly recommended and adopted in 1913 by the American Railway Master Mechanics' Association and the American Society for Testing Materials. A summary of data relative to Steel vs. Iron Flues and Tests applied to "NATIONAL" Boiler Tubes.

"NATIONAL" BULLETIN No. 2—CORROSION OF HOT WATER PIPING IN BATH HOUSES (eight pages, two illustrations). This Bulletin contains a report of an investigation conducted by Ira H. Woolson, M. Am. Soc. M. E., Consulting Engineer to National Board of Fire Underwriters, New York City, relative to the corrosion of iron and steel in hot water piping in a New York bath-house system. 89 samples of pipe from various bath houses were collected, and from the evidence, Mr. Woolson arrived at the following conclusion:

"In my judgment, from the evidence collected, there was absolutely no difference in the corrosion of the two classes of pipe.* They appeared to be equally susceptible to the attack."

*That is, wrought iron and steel.

This Bulletin also contains a paper on "The Design of Hot Water Supply Systems to Minimize Corrosion", by F. N. Speller, Metallurgical Engineer, National Tube Company, published in Engineering News, issue February 13, 1913. This paper is particularly valuable in that the suggested designs tend to reduce corrosion of pipe to a minimum.

"NATIONAL" BULLETIN No. 3—THE DURABILITY OF WELDED PIPE IN SERVICE (eight pages, two illustrations). This Bulletin contains a paper prepared by F. N. Speller, Metallurgical Engineer, National Tube Company, read before the annual meeting of the American Society of Heating & Ventilating Engineers and published in "Engineering Review", April, 1911. This article covers considerable information relative to the durability of welded pipe as found under various conditions; also detailed notes on corrosion of wrought iron and steel pipe in service lines in over 21 separate investigations, and the net results obtained in each case are compiled and tabulated, with some notes regarding the prevention of corrosion in pipes.

"NATIONAL" BULLETIN No. 4—CORROSION OF BOILER TUBES (12 pages, 33 illustrations). This Bulletin contains an abstract from a paper on "Corrosion of Boiler Tubes", covering a report of results obtained in an investigation by Rear Admiral John D. Ford, U. S. N., member and President of the American Society of Naval Engineers. The entire report was published in the Journal of American Society of Naval Engineers, May, 1904, and from it the abstract for this Bulletin was taken. The report covers a very full investigation relative to the comparative corrosion of wrought iron and steel boiler tubes. The tests continued over a period of 64 weeks. The Bulletin contains several tables of summaries of results, which indicate least, greatest and average loss in grammes per square inch. Also summary of various corrosion tests of wrought iron and steel, and particularly a table showing summary of results of investigations. Several different and independent investigations are referred to, giving date, locality, length of time of service, authority of test, number of cases on record, reference to details, remarks, etc., etc.

"NATIONAL" BULLETIN No. 5—"NATIONAL" PIPE FOR REFRIGERATING SYSTEMS (36 pages, 27 illustrations). This Bulletin contains information relative to the several types of systems employed in refrigerating work, with a brief statement of principles upon which the two most commonly used systems are based—The Compression and Absorption systems—together with a short discourse on the relative merits of "NATIONAL" and Wrought Iron pipe for refrigerating work. In addition there are two papers of general interest to all those interested in this subject—"Steel Pipe vs. Wrought Iron Pipe in Refrigerating Work" by P. DeC. Ball and "Corrosion of Pipe in Refrigerating Systems" by F. N. Speller, considerable engineering data applying to refrigerating work and a list of all "NATIONAL" Bulletins, Nos. 1 to 24, inclusive.

"NATIONAL" BULLETIN No. 6—PIPE THREADING DIES (12 pages, 21 illustrations). Because this subject is more or less misunderstood, the information contained in this Bulletin is especially valuable. The illustrations clearly demonstrate by comparison the working of a properly and improperly shaped die. The information is grouped under the following headings: "Lip", "Chip Space", "Clearance", "Lead", "Number Chasers", "Oil", "General Summary", and an article on the "Briggs' Standard" Thread.

"NATIONAL" BULLETIN No. 7—"N. T. C." REGRINDING VALVES (eight pages, seven illustrations). The particular advantages of this type of valve are described in detail in this Bulletin. Three illustrations show a valve, from photographs taken at three different angles, which was opened and closed 327,094 times. The valve was then reground and after being opened and closed over three million times is still in service! The various headings will afford some idea of the value of the contents: "Durability", "Construction", "Types of Discs", "Bonnet", "Body", "Bonnet Ring", "Stem", "Packing Under Pressure", "Packing Gland", "Metal", "Lift", "Wheel", "Testing", "Working Pressure", "Patterns" and "General Summary".

"NATIONAL" BULLETIN No. 8—"NATIONAL" COATING (eight pages, eleven illustrations). This Bulletin describes in detail a new method of protecting underground piping systems against external corrosion and electrolysis, known as "NATIONAL" Coating. The headings indicate the scope of the information: "Necessity for Protection Other than That Afforded by the Use of Good Steel", "Process of Applying 'NATIONAL' Coating", "Summarizing the Advantages of 'NATIONAL' Coating", "Suggestions Regarding the Laying of Pipe Covered with 'NATIONAL' Coating", "Specifying".

"NATIONAL" BULLETIN No. 9—SOME TESTS OF "KEWANEE" UNIONS (eight pages, five illustrations). This Bulletin contains a full description of several special tests made on "KEWANEE" Unions, including the following: Expansion Test of "KEWANEE" Unions, with tabulated details; Air Test Under Water of "KEWANEE" Unions (the test to which every individual "KEWANEE" Union is subjected before leaving the factory), with illustrations; Service Test on "KEWANEE" Unions (illustrations of two "KEWANEE" Unions which were disconnected and reconnected over 1000 times, and remained tight at the end of the test). The headings indicate something of the information given: "Inspections and Tests", "Construction", "Three Solid Parts", "Brass to Iron Thread Connection at the Ring", "Patterns", "Summary of Advantages".

"NATIONAL" BULLETIN No. 10—RELATIVE CORROSION OF IRON AND STEEL PIPE AS FOUND IN SERVICE (24 pages, 20 illustrations). This Bulletin contains abstract from a paper by William H. Walker, Ph. D., read before the New England Water Works Association, December 13, 1911, and which related in detail the results of an investigation undertaken by Professor Walker with reference to the subject indicated. Something like 64 comparisons of iron and steel were obtained where the history of installation was known. Prof. Walker's conclusion follows:

"These results again demonstrate that taken on the average there is no difference in the corrosion of iron and steel pipe. Conversations held with the engineers in charge of plants during this investigation confirm the statement already made that a pipe is frequently called steel when corrosion is found to be excessive, while it is set down as iron if it rusts but little."

This Bulletin also contains several papers by F. N. Speller, Metallurgical Engineer, National Tube Company, on the relative merits of steel and wrought iron pipe.

"NATIONAL" BULLETIN No. 11—HISTORY, CHARACTERISTICS AND THE ADVANTAGES OF "NATIONAL" PIPE (48 pages, 33 halftones, 57 zinc etchings). This bulletin contains interesting information relative to the history of pipe and its manufacture with particular reference to "NATIONAL" Pipe, together with authenticated data on service tests. The text is arranged under the following heads: A Short History of Pipe and Early Methods of Manufacturing, First American Pipe Furnace, History of National Tube Company, Material for Pipe, The First Steel Pipe, Pipe Threading, Spellerizing "NATIONAL" Pipe, Full Standard Weight Pipe Only Manufactured, The Continuous Uniformity of "NATIONAL" Pipe, Physical Properties, Remarkable Ductility of "NATIONAL" Pipe, Bursting Pressure, The Inspection and Tests of "NATIONAL" Pipe, Changes in the Tubular Industry, "NATIONAL" Pipe for Refrigerating Systems, Corrosion of Pipe in Hot Water Systems, The Design of Hot Water Supply Systems to Minimize Corrosion, Corrosion of Pipe in Coal Mines, Corrosion of Pipe in General Service, Corrosion of Pipe in Green House Service, "NATIONAL" Pipe for Gas Lines, Corrosion of Pipe in Boiler Feed-water Service, Relative Corrosion of Iron and Steel Pipe for Plumbing Service, A Summary of Results of Investigations of the Corrosion of Iron and Steel Pipe in Actual Service, Corrosion of Iron and Steel Pipe Under Atmospheric Conditions, diagrammatic representations of the merits of "NATIONAL" Pipe compared to Wrought Iron and Ordinary Steel Pipe with references, Index to important subjects covered in Bulletin, and a summarized list of "NATIONAL" Bulletins Nos. 1 to 23, inclusive.

"NATIONAL" BULLETIN No. 12—CHARACTERISTICS OF "NATIONAL" PIPE (twenty pages, seven illustrations). This Bulletin contains a summary of information in regard to "NATIONAL" Pipe. The data is supplied under the following headings: Steel Pipe, Uniformity, Physical Properties, Chemical Composition, Improvements, Full Weight Pipe, Spellerizing, Threading, Corrosion (résumé of opinions), Specifications, Metallurgical Dept., Literature, Summary of Advantages, list of uses of "NATIONAL" Pipe, four charts illustrating graphically the "Rise of Steel Pipe" based on statistics compiled by The American Iron and Steel Institute and published in Special Statistical Bulletin No. 8, and list of publications issued by National Tube Company.

"NATIONAL" BULLETIN No. 13—"N. T. C." IRON BODY BRASS MOUNTED WEDGE GATE VALVES (12 pages, 21 halftone and 8 line illustrations). Contains complete information in regard to this new line of wedge gate valves.

"NATIONAL" BULLETIN No. 14—"NATIONAL" TUBULAR STEEL POLES (32 pages, 25 halftone and 2 line illustrations). This Bulletin contains a complete description of these poles, the information is supplied under the following headings: Uniformity, Lighting, Physical Properties, Joints, Dog Guards, Street Railway Poles, Painting, Pole Tables, Pole Fittings, Specifications, etc. There are also ten pages of pole tables giving full information in regard to poles.

"NATIONAL" BULLETIN No. 15—"NATIONAL" PIPE FOR DRILLING PURPOSES (8 pages, 6 halftone illustrations). This Bulletin contains a full description of this product, the information is supplied under the following captions: Process of Manufacture, Material, Physical Properties, Bending Tests on Welded Pipe, Internal Pressure Test, Length, Permissible Variations, Upsetting, Threading and Reaming, Couplings, Marking, Finish, Inspection, Galling of Threads, Strength of Joint, Torsional Tests with Tables, "NATIONAL" Drill Pipe with Table, "NATIONAL" Special Rotary Pipe with Table, "NATIONAL" Special Upset Rotary Pipe with Table, "NATIONAL" Seamless Interior Upset Drill Pipe with Table, Precautions in Handling Drill Pipe, and Trade Customs.

"NATIONAL" BULLETIN No. 16—"NATIONAL" STATIONARY AND MARINE BOILER TUBES (12 pages, 8 halftone illustrations). This Bulletin contains a description of these boiler tubes with illustrations of tests. The information is supplied under the following heads: Reasons for Manufacturing Only Steel Tubes, Spellerizing, Material, Physical Properties, Inspection, Physical Tests, Opinions of Experts, etc.

"NATIONAL" BULLETIN No. 17—THE MANUFACTURE AND USE OF "SHELBY" SEAMLESS STEEL TUBING (44 pages, 25 halftone plates and 5 pages of line engravings, showing various manipulations of "SHELBY" Seamless Steel Tubing). This Bulletin contains extracts from an address to the U. S. Naval School of Marine Engineering (prepared by Messrs. J. H. Nicholson and Emil Holinger) and covers the following subjects: Process of Manufacture; Materials for Steel Pipes; Making of Specifications; Mill Inspection; Application of Tubular Sections to Machine Design, and Descriptions of the Halftone Plates.

"NATIONAL" BULLETIN No. 18—"NATIONAL" REAMED AND DRIFTED PIPE (12 pages, 33 halftone illustrations). This Bulletin contains a complete description of this product, with a short introduction explaining the process of Well Drilling and information relative to the various accessories necessary for the drilling and pumping of wells. For example—Well Cylinders, Points, Valves, Strainers, Drive Shoes, Couplings, Dripe Caps, Seating Tool, etc.

"NATIONAL" BULLETIN No. 19—LIST OF PRODUCTS (eight pages, no illustrations). To supply a quick and ready reference is the purpose of this Bulletin. The products manufactured by this company are designed for a great variety of mechanical and commercial purposes, hence a single catalogue containing a detailed description of each separate product would be cumbersome. This Bulletin contains a concise list, which gives to the trade reliable information of National Tube Company products.

"NATIONAL" BULLETIN No. 20—INDEX OF "NATIONAL" BULLETINS 1 to 20 (32 pages, 5 illustrations). This Bulletin is a cross-indexed guide to the information contained in all "NATIONAL" Bulletins from 1 to 20.

"NATIONAL" BULLETIN No. 21—"NATIONAL" BEDSTEAD TUBING (eight pages, ten illustrations). This Bulletin gives much information and data, and shows the advantages of using "NATIONAL" Tubing in the manufacture of modern steel beds, cribs, bungalow beds, bed springs, costumers, etc.

"NATIONAL" BULLETIN No. 22—"NATIONAL" PIPE FOR RAILWAY SIGNAL SERVICE (12 pages, 18 illustrations). This Bulletin contains a brief description of several classes of modern railway signal systems with illustrations of a number of installations in which "NATIONAL" Pipe has been used; Standard Signal Pipe Specifications, as approved by The Railway Signal Association, October, 1910; and considerable information relative to "NATIONAL" Pipe for this character of service. This information is given under the following headings: STRENGTH: Physical Properties, Chemical Purity, Resistance. DURABILITY and THREADING QUALITIES. In addition there is a brief summary of all "NATIONAL" Bulletins.

"NATIONAL" BULLETIN No. 23—"NATIONAL" DRY KILN PIPE (20 pages, 13 illustrations). This Bulletin contains information relative to this class of "NATIONAL" Pipe and its use. The text matter is grouped under the following headings: Material Used, Method of Manufacture, Uniformity, Chemical Composition, Physical Properties, Bursting Strength, Durability (Resistance to Corrosion), Full Weight, Special Treatments (Spellerizing), Threading Properties and Tests. There are also tables giving Weights and Dimensions of "NATIONAL" Dry Kiln Pipe and Couplings and "NATIONAL" Standard Pipe—Black and Galvanized, and considerable engineering data relating to Dry Kiln work, closing with a summary of all "NATIONAL" Bulletins, Nos. 1 to 23, inclusive.

"NATIONAL" BULLETIN No. 24—THE RISE OF STEEL PIPE (8 pages, 4 illustrations). This Bulletin contains three editorials, covering the general subject of "The Rise of Steel Pipe", which appeared in the American Metal Market and Daily Iron and Steel Report, August 20, 1914, The Iron Trade Review, October 15, 1914, and The Iron Age, December 3, 1914. There are some comments on these editorials, together with a list of advantages of "NATIONAL "Pipe and complete summary of "NATIONAL" Bulletins Nos. 1 to 24, inclusive.

"NATIONAL" BULLETIN No. 25—"NATIONAL" PIPE IN LARGE BUILDINGS (88 pages, 222 illustrations). This Bulletin contains a brief outline of the progress of the last twenty years in building construction; a summary of the advantages of "NATIONAL" Pipe service and the value of marking manufactured products as brought out in a recent editorial in The American Architect; a short summary of the results of tests and investigations of independent authorities relative to the durability of wrought iron and steel pipe; illustrations of Banking, Financial and Office Buildings, Mercantile and Industrial Buildings, Hotels, Clubs and Apartments, Universities, Colleges, Schools, Churches, Libraries and similar public buildings in which "NATIONAL" Pipe has been installed; "The Design of Hot Water Supply Systems to Minimize Corrosion" a paper by F. N. Speller, published in Engineering News, February 13, 1913; Specifications covering "NATIONAL" Standard Welded Pipe, "NATIONAL" Air Line Pipe, and "NATIONAL" Special Ammonia Pipe together with tables giving dimensions and weights; Engineering data extracted from "Book of Standards" 1913 Edition, National Tube Company, relative to piping and its use in building construction; an index to the important subjects and illustrations contained in this Bulletin and a short summary of all "NATIONAL" Bulletins Nos. 1 to 25, inclusive.

¶ To readily identify "NATIONAL" material and as protection to manufacturer and consumer alike, the practice of National Tube Company is to roll in raised letters of good size on each few feet of every length of welded pipe the name "NATIONAL" (except on the smaller butt-weld sizes, on which this is not mechanically feasible; on these smaller butt-weld sizes the name "NATIONAL" appears on the metal tag attached to each bundle of pipe).

LOOK FOR THE MARK

Name Rolled in Raised Letters on National Tube Company Pipe

¶ When writing specifications or ordering tubular goods, always specify "NATIONAL" pipe, and identify as indicated.

¶ In addition, all sizes of "NATIONAL" welded pipe below four or five inches are subjected to a roll-knobbling process known as Spellerizing to lessen the tendency to corrosion, especially in the form of pitting. This Spellerizing process is peculiar to "NATIONAL" pipe, to which process National Tube Company has exclusive rights.

NATIONAL TUBE COMPANY

General Sales Offices: Frick Bldg., PITTSBURGH, PA.

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